RAFA Solutions

Industrial Protocols Educational Software

InPEduS

CONTENTS

Introduction

"InPEduS" is educational software, which is intended to help students learn basics of industrial protocols and interfaces. Software is combined of interesting and useful exercises and demonstrations, which give a unique opportunity to deeply understand the structure and operation principles of protocols.

InPEduS software includes 9 popular protocols, which are CAN, GPIB, I2C, Modbus, RS232, RS485/422, SPI, TCP and UDP.

For each of the protocols from 1 to 3 exercises are designed that serve to test student's knowledge and help them to get the full idea of protocols. A demonstration is provided for each protocol, to visualize working mechanism of protocols. InPEduS also gives opportunity to make reports for finished exercises. This option can be helpful for trainers as well as for students to have information about student's progress.

InPEduS also provides User Manual with full descriptions of all protocols and instructions for exercises in order to perform them correctly. Software has also an option to open User Manual while working with protocols. This option makes it even more convenient for students to refresh their knowledge of protocols while doing exercises.

In conclusion, InPEduS is an adjuvant tool to make studying process of protocols fascinating. All options introduced above make it an ideal platform to learn industrial protocols course either by your own or within a class.

Required Software

Windows 7
LabVIEW Run-Time Engine 2012
MS Word 2010 or higher

Installation of the software

Install the following software:

1. Software “InPEduS” (run ***setup.exe*** and follow the instructions).

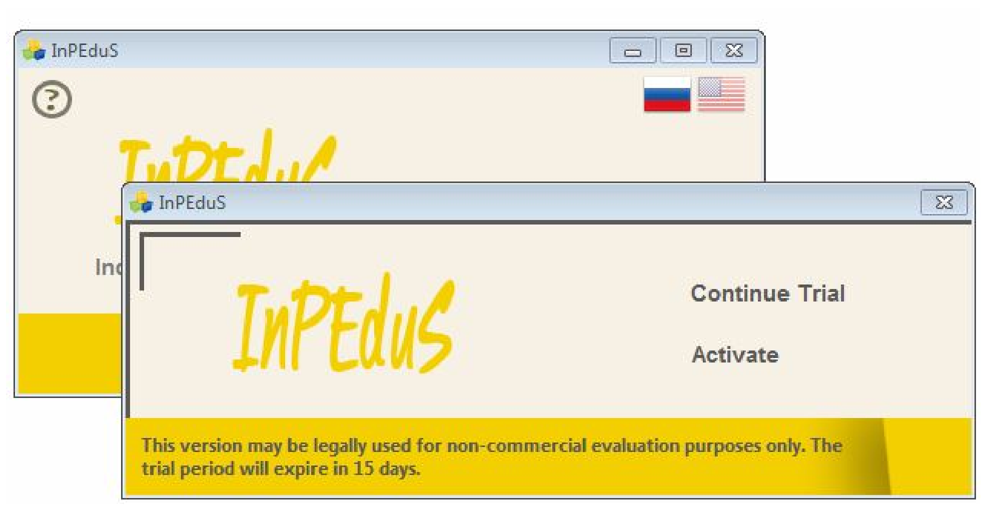
Please check if you have font “Arial CYR” on your computer. If the font does not exist, you can find it in the folder with installer.

If you are going to use Russian version of the software before running the software ensure MS Windows supports Russian keyboard. Open **Start -> Control Panel -> Regional and language Options** and make sure that location is set as Russia ***Location: Россия*** and in the tab ***Advanced*** language for non-Unicode programs is set - ***Русский***.

After installation is complete restart the computer.

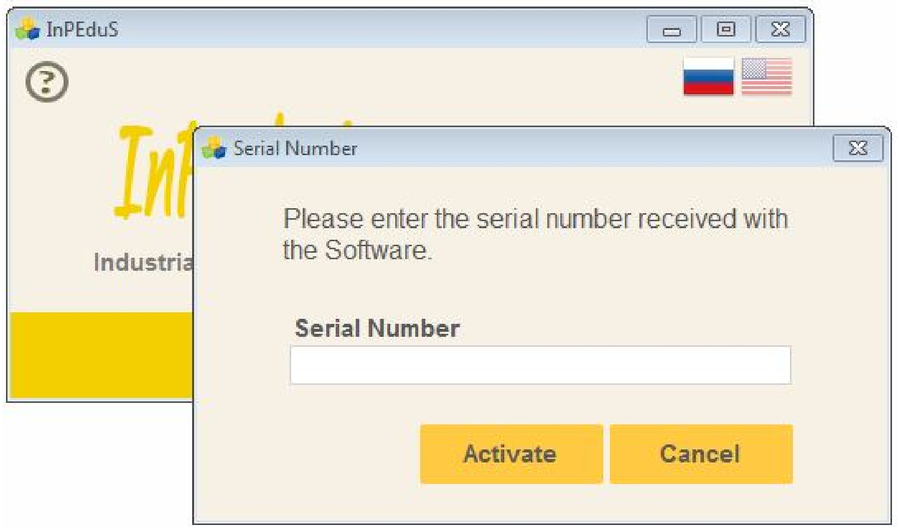
Software License and Evaluation

You can use the software without activation for 15 days for evaluation purposes. In this case you will see notification of days left each time you start the software.



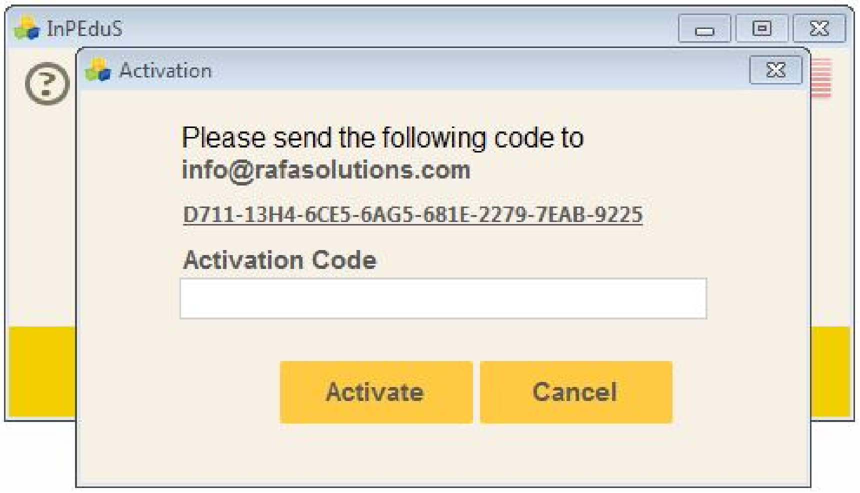
This version may be legally used for non-commercial evaluation purposes only. The trial period will expire in 15 days.

To activate software you should click the “Activate” button. The following window will be opened.



Please enter the serial number received with the Software.

Enter the Serial Number, which you were provided. If entered serial number is correct, the following window will be opened for final activation. Shown code should be sent to the provided email address to get activation code.

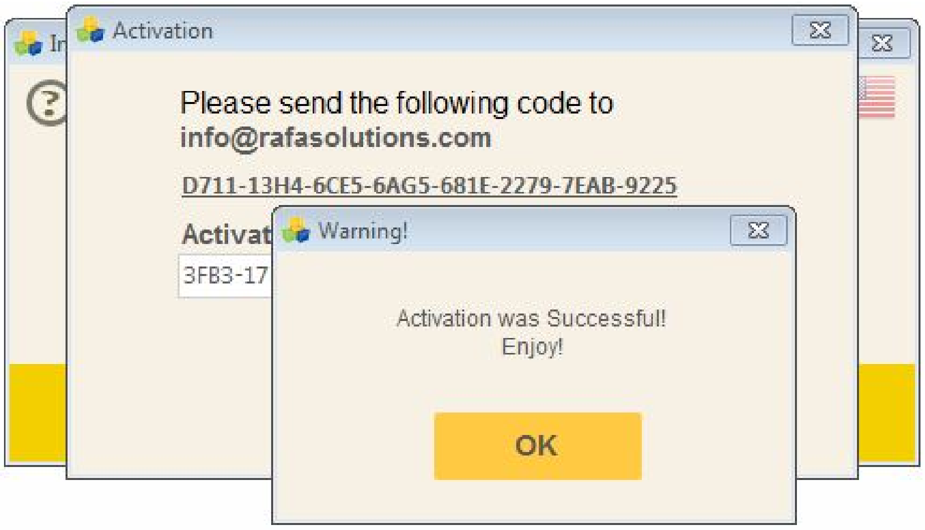


Please send the following code to
info@rafasolutions.com

D711-13H4-6CE5-6AG5-681E-2279-7EAB-9225

Activation Code

If entered activation code is correct, the following window will appear.



Please send the following code to
info@rafasolutions.com

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Activat

3FB3-17

Activation was Successful!
Enjoy!

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1. Protocol CAN

CAN (Controller Area Network) protocol was developed by Robert Bosch GmbH company in middle 1980-s and nowadays is broadly popular within IT, “smart house” technologies, vehicle diagnostics, etc.

Different messages which are being transmitted via network have identifier. Each station decides whether to receive message or no depending on the identifier. The identifier is defined in “identifier” field of CAN frame. In this mechanism Receiver address is being identified on receiver itself by installation of input filters of corresponding ICs.

CAN controllers are connected with differential bus, which has 2 lines for signal transmission: CAN_H (can-high) and CAN_L (can-low). Logical “0” is detected, if the signal on line CAN_H is higher than on the line CAN_L and logical “1” if signals on both lines are the same (signals are considered to be equal if difference between them is less than 0.5V). Use of this differential scheme makes possible the use of CAN network in very complicated situations. Logical “0” is called dominant bit and logical “1” recessive. These names reflect priorities of logical “0” and “1” on CAN bus. In case of simultaneous transmission of logical “0” and “1”, only logical “0” will be registered on bus, and the logical “1” will be ignored.

CAN protocol is constructed from the following levels.

1. Object level provides message filtering and processing of messages and states.
2. Transport level is the heart of CAN protocol. It provides synchronization, arbitrage, access to bus, seperation of messages into frames, error detection and error transmittion, and defect minimization.
3. Physical level defines the specific ways of signal transmission, electrical levels of signals and transmission speed. The typical values at 5V supply voltage are illustrated on Figure 1-1, lower level is dominant and higher is recessive.

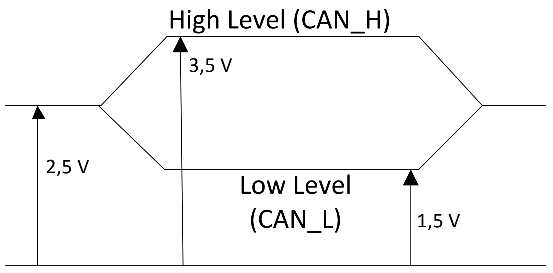


Figure 1-1 Signal levels on bus

Maximal distance between nodes is approximately 1 km. Transmission speed can reach up to 1 Mb/sec in case of 60 meter line length. The bus has possibility of galvanic isolation. The galvanic isolation can be set either between receiver-transmitter buffer and IC providing CAN functions or between IC and remaining system.

The following frame types are defined for CAN protocol:

- **Data Frame** transfers data from transmitter to receiver(s);
- **Remote Frame** requests data frame from the node with the specified identifier;
- **Error Frame** defines the node where bus/network error was detected;
- **Overload Frame** provides delay between frame transmissions, for data flow control.

Data Frame

On Figure 1-2 the data frame structure is shown.

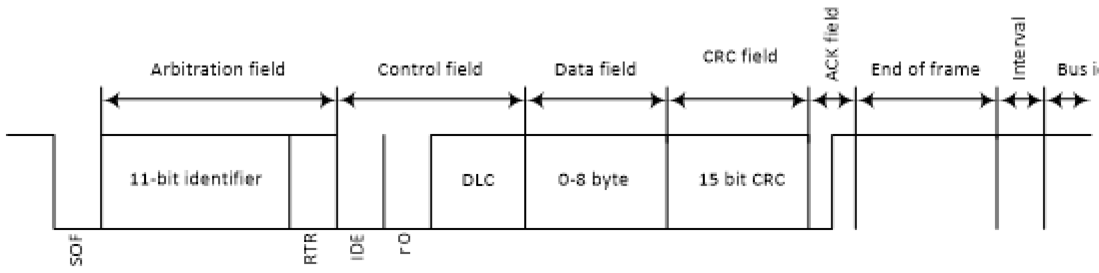


Figure 1-2 Data frame structure

Standard frame consists of the following fields:

- **Start of Frame (SOF)**. SOF field is located at the start of data frame and remote frame, it contains one dominant bit.
- **Arbitration Field**. Arbitration field is combined of 11-bit identifier and RTR bit, identifying if the frame is data frame or remote frame. If the frame is data frame RTR bit is being set to logical “0” (dominant signal). Identifier is designed for message addressing and is used for arbitration mechanism. For CAN-2.0A standard 11-bit identifier is used and for CAN-2.0B 29-bit identifier is used.
- **Control Field.** Control Field (Figure 1-3) contains 6 bits, 4 of which (DLC0-DLC4) compose Data Length Code field, which identifies the number of data bytes to be transmitted, 2 other bits are reserved for later versions of the protocol.

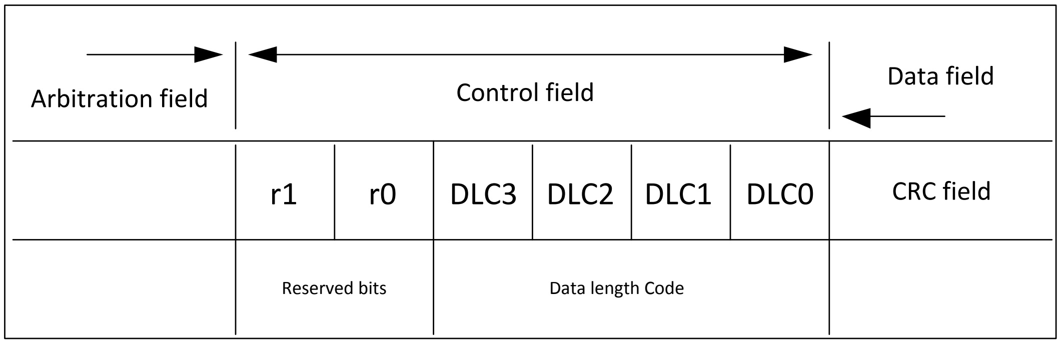


Figure 1-3 Data Frame Control Field

The data byte number coding by data field size code is given in the Table 1-1.

Table 1-1 Data byte number coding

Data byte number	Data field size code			
	DCL3	DCL2	DCL1	DCL0
0	dom.	dom.	dom.	dom.
1	dom.	dom.	dom.	rec.
2	dom.	dom.	rec.	dom.
3	dom.	dom.	rec.	rec.
4	dom.	rec.	dom.	dom.
5	dom.	rec.	dom.	rec.
6	dom.	rec.	rec.	dom.
7	dom.	rec.	rec.	rec.
8	rec.	dom.	dom.	dom.

- **Data Field.** Data field contains transmitting data, and number of transmitting bytes is defined in Control Field and cannot be more than 8.
- **Cyclic redundancy check (CRC).** CRC field (Figure 1-4) contains cyclic redundancy code, for error detection in all previous fields of the frame, including start bit. Each receiver node calculates CRC value for each received message. If the calculated CRC and CRC value within message differ, the receiver node generates CRC Error.

For calculation of CRC polynomial, the polynomial, which coefficients are being given through data flow combined from bits of fields: “Start field”, “Arbitrate Field”, “Data Control Field” and “Data field” (if exists) (15 least sygnificant coefficients of polynimial are set to 0) should be devided to polynomial of the following form:

$$x^{15} + x^{14} + x^{10} + x^{8} + x^{7} + x^{4} + x^{3} + 1$$

The remainder of this polynomial division is the CRC series transmitted through bus. The CRC field ends with CRC separator (one recessive bit).

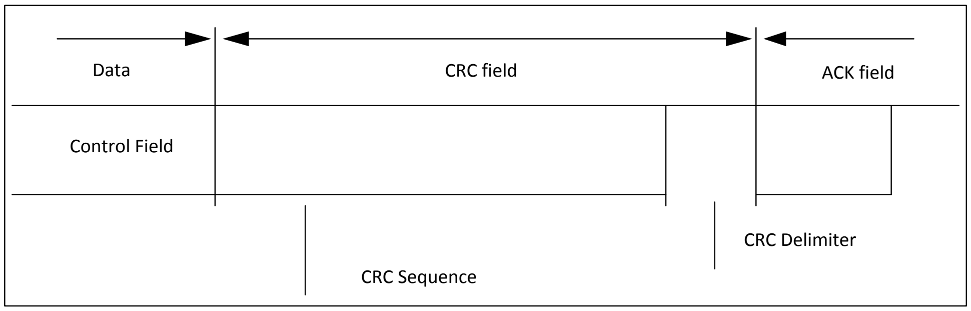


Figure 1-4 Data frame CRC field

ACK Field. Acknowledgment field (Figure 1-5) contains segments ACK Slot and ACK Delimiter and has the following functions: transmitter node sends a recessive bit on each segment and the receiver, if it received message without any failure, sets dominant bit on line in ACK Slot Field. In case of setting recessive and dominant levels, the dominant bit is being set on line, this event signals transmitting node that transmission was successful and there is no need for repeat. Second bit of this field (ACK Delimiter) is always recessive.

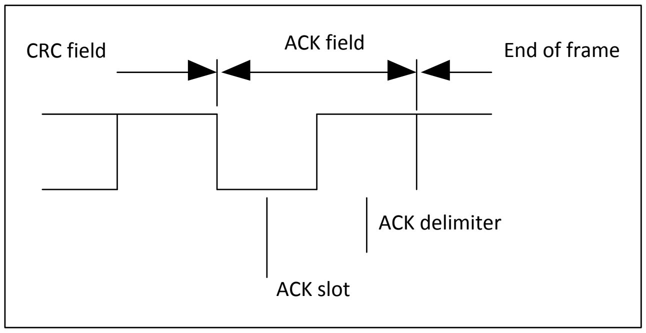


Figure 1-5 Data Frame Acknowledgment Field

- **End of Frame (EOF).** End of Frame is set in data frame and remote frame and is compound of seven recessive bits.

Remote Frame

With its structure remote frame is analogical to data frame, with minor difference, that it doesn't have data field. Remote frame is constructed from: Start field, Arbitration field, Control field, CRC field, ACK field and End of frame (Figure 1-6). In case of remote frame, RTR bit is recessive. The polarity of RTR bit defines whether transmitted frame is data frame (dominant RTR bit) or remote frame (recessive RTR bit).

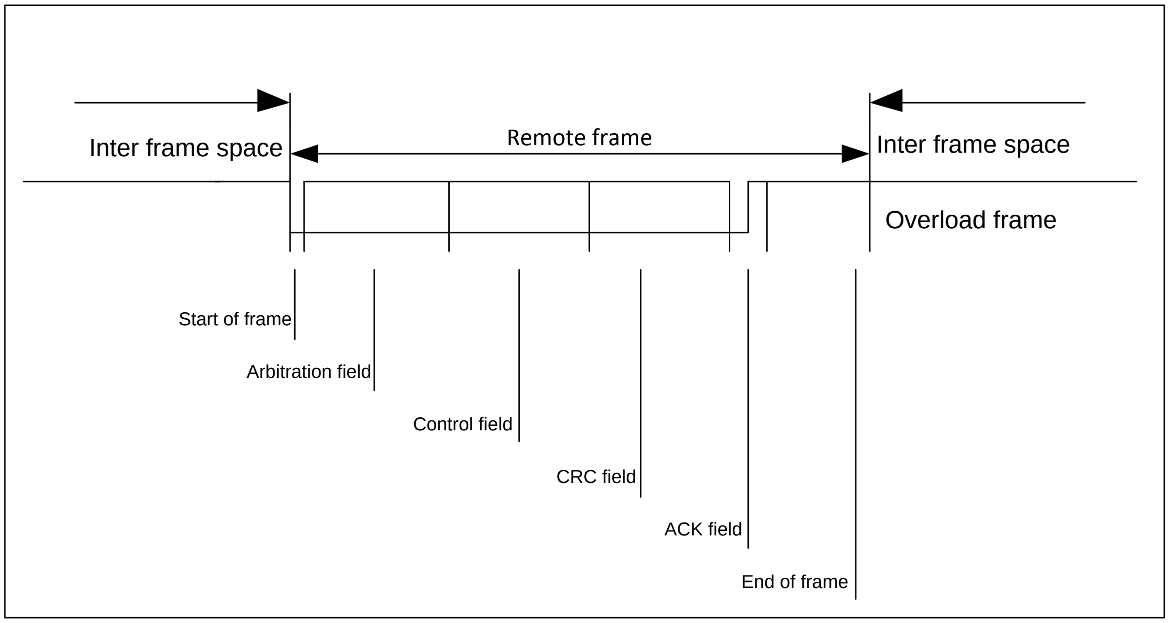


Figure 1-6 Remote Frame

Error Frame

Error frame is used by any receiver node, to inform all segments of network about existence of an error in the transmitted message. Error message has the highest priority in the system, it is being transmitted right after error is detected and is received by all devices simultaneously. The message with error is being deleted from memory of all devices simultaneously.

Error frame consists of two different fields (Figure 1-7). First field is given through superposition of **Error Flags** (6 dominant bits in case of active error flag/ 6 recessive bits in case of passive error flag), which are set by two different stations. Second field is **Error Delimiter** (8 recessive bits).

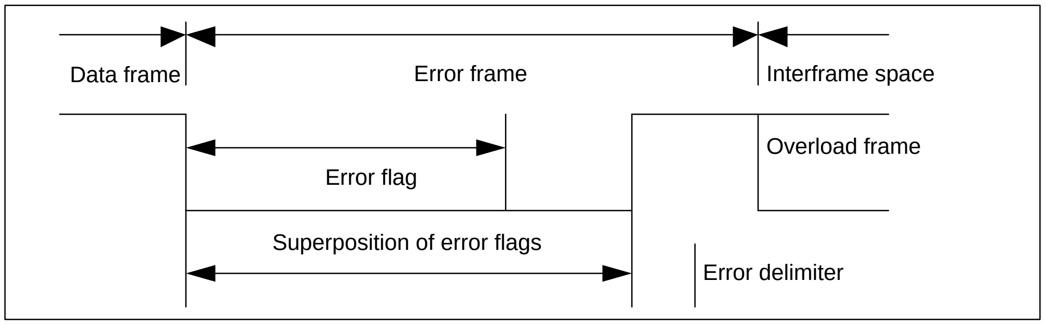


Figure 1-7 Error Frame

Overload Frame

Overload frame consists of two fields: overload flag and delimiter field. There are several conditions in case of which transmit of overload frame is being operated:

- Receiver overload, which requires increase of delays between received messages.
- Dominant bit detection in place of first and second bits of delay between frames.

Interframe Space (IFC) is being set between data frames, calling frame and any other frames. Opposite to this, there is no delay before overload frame and error frame, which speeds up receive of these fields.

Interframe Space consists of **Intermission** (3 recessive bits) and **Bus Idle** (of arbitrary length) and in case of devices passive to error, which have operated transmit of last message, **Suspend Transmission**.

Error Detection in CAN protocol

CAN protocol defines five methods of error detection in network:

- Bit monitoring
- Bit stuffing
- Frame check
- ACKnowledgement Check
- CRC Check

Bit monitoring – each node compares transmitted bit with the bit on the bus during bit transmission to network. Node generates Bit Error if these values do not equal. This mechanism of error detection is turning off during arbitration field transmission.

Bit stuffing – After transmit of five serial equivalent bits, transmitter automatically puts in flow a bit of opposite polarity. Message receivers automatically delete these bits before message processing. If the 6-th bit of the same polarity is detected, bit overload error is flagged. If the error is detected, the node sends error message and interrupts the transmission. In this case transmitter repeats message transfer, which protects all nodes from error generation and provides data consistency within network.

Frame check – some segments of CAN message have equal values within all message types. This means that CAN protocol defines what voltage levels should appear on the bus and when. If the message format is broken, nodes generate Form Error.

ACKnowledgement Check – each node sends to network dominant (0) bit after receiving correct message. If this action doesn't take place, transmitting node registers Acknowledgement Error.

CRC Check – each CAN message has within it CRC sum, and each receiver node calculates CRC value for each received message. If the calculated CRC value does not equal to the value of CRC in the message, receiver node generates CRC Error.

Access Control (bitwise arbitration)

In CAN protocol all nodes get the message from transmitter node and confirm it. Each time, when bus is transfer free, a node can start transmission. Next transmission can be started only after current transmission process is finished. If two or more nodes start transferring simultaneously, the conflict is being resolved in terms of non-destructive bitwise algorithm of arbitration, which uses the arbitration field.

11-bit identifier field is transferred from the most significant to the least significant bit. During transmission of arbitration field each transmitter controls current level on the bus, which it should transfer. If the values equal, node then can continue transmission. If a recessive bit was transmitted, and dominant bit is detected on the bus, transmission should stop immediately and the node loses transmission access (Figure 1-8). This node can attempt to start new transfer only after current transfer is finished.

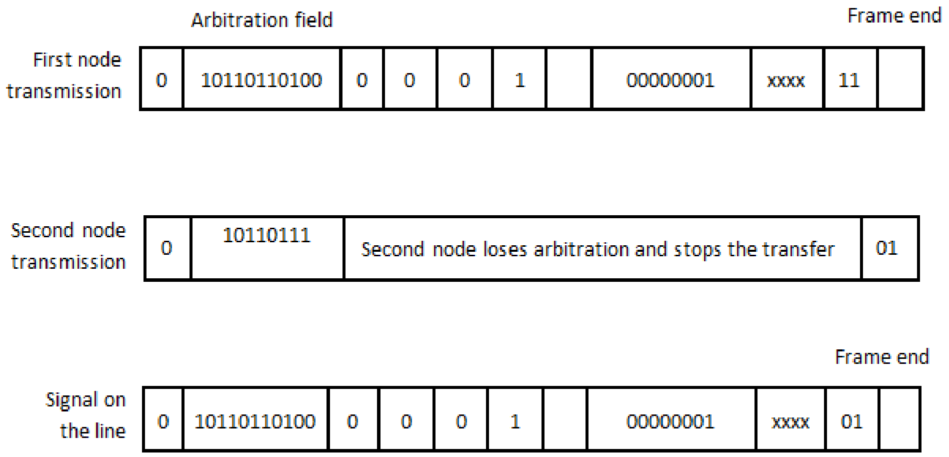


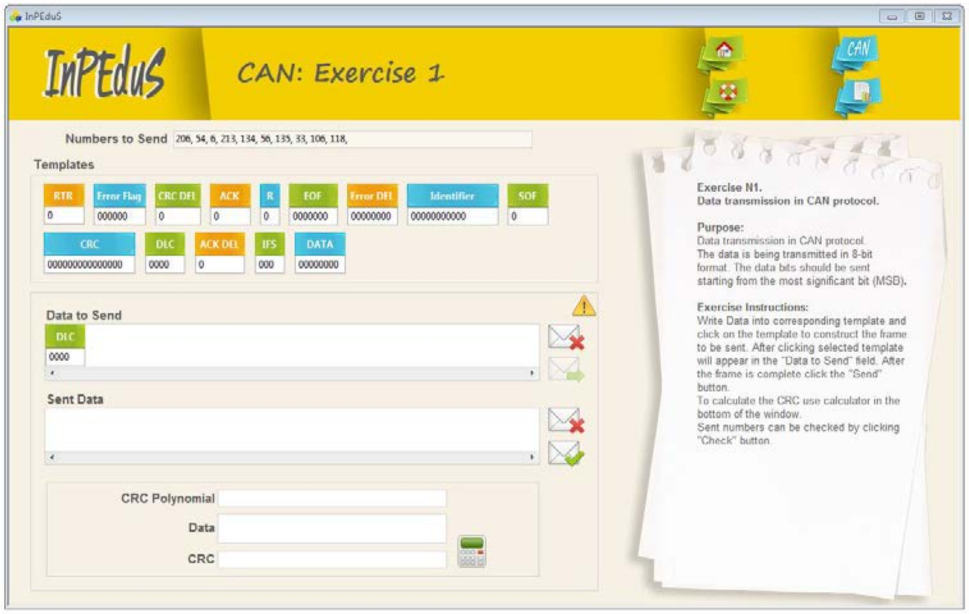
Figure 1-8 Bitwise Arbitration Example

To conclude, the priority is defined not by transmitter or receiver nodes but by the value of identifier within the message. The smallest identifier has the highest priority. From operating nodes, only the node with the smallest identifier value can be responsible for decisions made.

The other opportunity of the arbitration mechanism is used in the highest level network of DeviceNet. In this network the maximum number of nodes is 64, and the least significant digits of the identifier are used for addressing, and the most significant digits are specified for message type coding. The message with 0 in the most significant bit will occupy the bus first, independent on receiver node address. This, in turn, provides transfer of first type messages at first, independent on transmitter and receiver addresses.

Exercise №1. Data transmission in CAN protocol.

The purpose of the exercise is a study of data transmission in CAN protocol.



Numbers to Send 206, 54, 6, 213, 134, 56, 135, 33, 106, 118,

RTR	Error Flag	CRC DEL	ACK	R	EOF	Error DEL	Identifier	SOF
0	000000	0	0	0	0000000	00000000	00000000000	0

CRC	DLC	ACK DEL	IFS	DATA
000000000000000	0000	0	000	00000000

DLC
0000

Exercise N1.
Data transmission in CAN protocol.

Purpose:
Data transmission in CAN protocol.
The data is being transmitted in 8-bit format. The data bits should be sent starting from the most significant bit (MSB).

Exercise Instructions:
Write Data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the "Data to Send" field. After the frame is complete click the "Send" button.
To calculate the CRC use calculator in the bottom of the window.
Sent numbers can be checked by clicking "Check" button.

The data is being transmitted in 8-bit format. The data bits should be sent starting from the most significant bit (MSB).

The program generates numbers to be sent automatically. These numbers are given in the **“Numbers to Send”** field on the top of the window.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the **“Data to Send”** field. After the frame is complete click the **“Send”** button.

In case of error within the frame Warning Indicator will turn red. Click the **“Clear”** button and assemble the frame once more. You can send all the numbers within one frame or each number within separate frames.

To calculate the CRC use calculator in the bottom of the window. Write down the polynomial in the **“CRC Polynomial”** field. Fill the **“Data”** field, and click **“Calculate CRC”** button afterwards.

If the frame is constructed correctly, it will appear in the **“Sent Data”** field after clicking **“Send”** button. Sent numbers can be checked by clicking **“Check”** button. If the numbers within the frame are correct, the dialog box will appear with “Correct!” text, the dialog with “Incorrect!” text will appear in opposite case. Clear **“Data to Send”** and **“Sent Data”** fields in this case and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **“Report”** button to create the report.

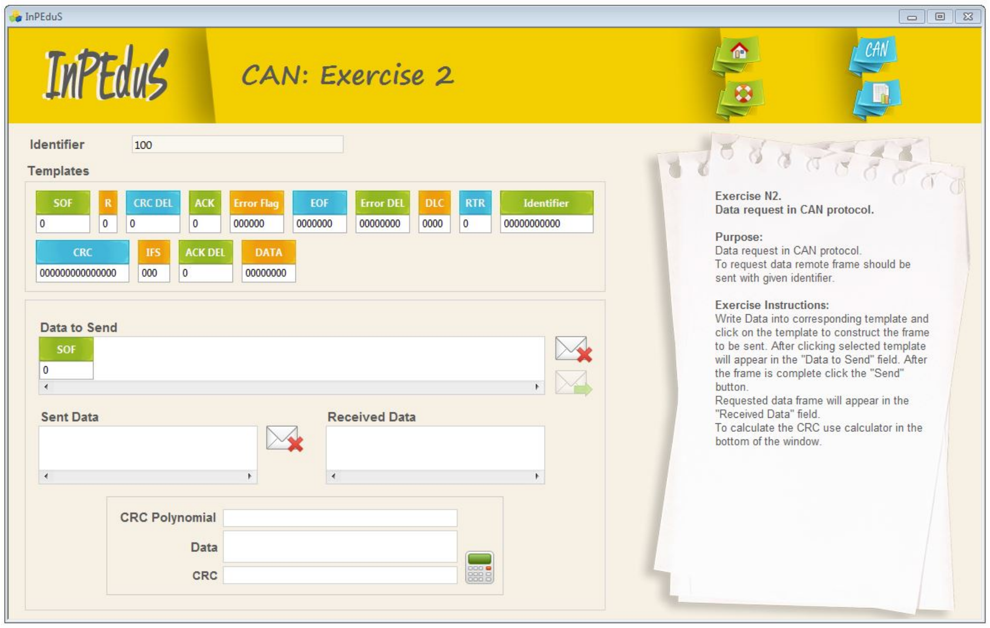
If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

Exercise №2. Data request in CAN protocol.

The purpose of the exercise is the study of data request in CAN protocol.



Identifier: 100

SOF	R	CRC DEL	ACK	Error Flag	EOF	Error DEL	DLC	RTR	Identifier
0	0	0	0	000000	0000000	00000000	0000	0	00000000000

CRC	IFS	ACK DEL	DATA
000000000000000	000	0	00000000

Data to Send: SOF 0

Exercise N2.
Data request in CAN protocol.

Purpose:
Data request in CAN protocol.
To request data remote frame should be sent with given identifier.

Exercise Instructions:
Write Data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the "Data to Send" field. After the frame is complete click the "Send" button.
Requested data frame will appear in the "Received Data" field.
To calculate the CRC use calculator in the bottom of the window.

To request data remote frame should be sent with given identifier.

The program generates identifier code automatically, which is displayed in **“Identifier”** field at the top of the window.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding templates and click on the templates to construct the remote frame. After clicking, selected template will appear in the “**Data to Send**” field. After the frame is complete click the **“Send”** button.

In case of error within the frame Warning Indicator will turn red. Click the **“Clear”** button and assemble the frame once more.

To calculate the CRC use calculator in the bottom of the window. Write down the polynomial in the **“CRC Polynomial”** field. Fill the **“Data”** field, and click **“Calculate CRC”** button afterwards.

If the frame is constructed correctly, it will appear in the **“Sent Data”** field after clicking **“Send”** button and the received data frame will appear in the field **“Received Data”**.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **“Report”** button to create the report.

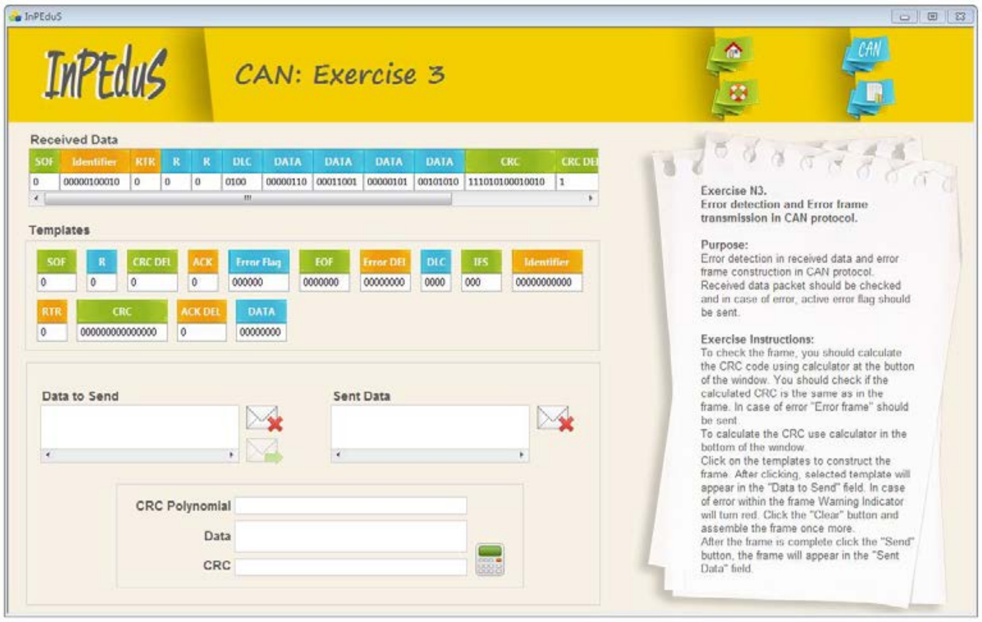
If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

Exercise №3. Error detection and Error frame transmission in CAN protocol.

The purpose of this exercise is to check received data and to send error frame in CAN protocol. Received data packet should be checked and in case of error, active error flag should be sent.



Received Data

SOF	Identifier	RTR	R	R	DLC	DATA	DATA	DATA	DATA	CRC	CRC DEL
0	00000100010	0	0	0	0100	00000110	00011001	00000101	00101010	111010100010010	1

Templates

SOF	R	CRC DEL	ACK	Error Flag	EOF	Error DEL	DLC	IFS	Identifier
0	0	0	0	000000	0000000	00000000	0000	000	00000000000

RTR	CRC	ACK DEL	DATA
0	000000000000000	0	00000000

Data to Send

Sent Data

CRC Polynomial

Data

CRC

Exercise N3.
Error detection and Error frame transmission in CAN protocol.

Purpose:
Error detection in received data and error frame construction in CAN protocol. Received data packet should be checked and in case of error, active error flag should be sent.

Exercise Instructions:
To check the frame, you should calculate the CRC code using calculator at the button of the window. You should check if the calculated CRC is the same as in the frame. In case of error "Error frame" should be sent.
To calculate the CRC use calculator in the bottom of the window.
Click on the templates to construct the frame. After clicking, selected template will appear in the "Data to Send" field. In case of error within the frame Warning Indicator will turn red. Click the "Clear" button and assemble the frame once more.
After the frame is complete click the "Send" button, the frame will appear in the "Sent Data" field.

The program generates the frame to check automatically, which is displayed in **"Received Data"** field at the top of the window.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

To check the frame, you should calculate the CRC code using calculator at the button of the window. You should check if the calculated CRC is the same as in the frame. In case of error **"Error frame"** should be sent.

Click on the templates to construct the frame. After clicking, selected template will appear in the "**Data to Send**" field. In case of error within the frame Warning Indicator will turn red. Click the **"Clear"** button and assemble the frame once more.

After the frame is complete click the **"Send"** button, the frame will appear in the **"Sent Data"** field.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **"Report"** button to create the report.

If the exercise is not finished after **"Report"** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

2. Protocol SPI

SPI (Serial Peripheral Bus) is an interface for serial data transfer between chips, which was developed by Motorola. Nowadays it is widely used in productions of many companies. SPI is also called four-wire interface. SPI bus is organized by master - slave principle. Microcontroller usually serves as master and different chips, memories, specialized controllers, etc. are slaves.

SPI interface is a protocol of data transfer between two shift registers, each of which is both a receiver and a transmitter simultaneously. The generation of bus synchronization signal is a precondition for data transfer through SPI bus. This signal can be generated only by master.

4 signals are involved in data transmission with SPI protocol.

- MOSI or SI —Master Out Slave In. Serves for data transmission from master to slave.
- MISO or SO —Master In Slave Out. Serves for data transfer from slave to master.
- SCLK or SCK —Serial Clock. Serves for transmission of clock signal to slaves.
- CS or SS —Chip Select, Slave Select.

There are 3 connection types on SPI bus. The simplest connection, where only 2 chips are included, is shown on Figure 2-1. Here, master sends data by MOSI line, synchronized with SCLK signal, which is as well generated by master. The slave receives transmitted data bits by fronts of received synchronization signal, simultaneously with this process slave sends its data packet. If there is no need of response data transfer, the illustrated scheme can be simplified, by excluding the MISO line.

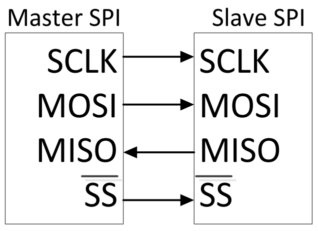


Figure 2-1 Simplest connection on SPI bus

If there is need for connection of several chips to SPI bus, either parallel connection or cascaded (serial) connection is used. In case of cascaded connection, multiple slaves can be connected to one line.

Standard algorithm for SPI functioning is given below.

1. Master sets low level on the SS line, to which linked slave is connected.
2. Master generates clock signal, switching signal level of SCLK between “0” and “1”. Master puts the right level of MOSI signal simultaneously with every SCKL level change, so during each clock pulse it sends one data bit to slave.
3. Slave puts right MOSI level with each SCKL level change, so it sends to master one bit during each clock pulse.
4. Master sets high signal level on SS line, to finish the transmission.

SPI is full duplex bus. Data is transferred in both directions simultaneously (Figure 2-2). The speed of the bus usually is in range of 1-50 MHz. Because of its simplicity, SPI has become widely used in different electrical devices such as sensors, memory chips, etc.

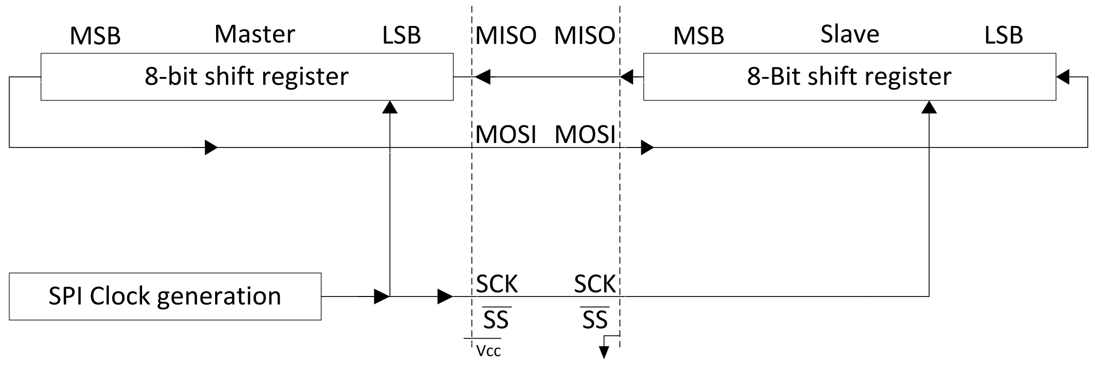


Figure 2-2 Full duplex data transfer

SPI interface uses 2 registers to set data transfer parameters (synchronization signal frequency, transmission mode, etc.): control register (SPCR) and status register (SPSR). SPI status and control registers are given in Table 2-1 and Table 2-2.

Table 2-1. SPCR

Digit	7	6	5	4	3	2	1	0
Flag	**SPIE**	**SPE**	**DORD**	**MSTR**	**CPOL**	**CPHA**	**SPR1**	**SPR0**
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Init. value	0	0	0	0	0	0	0	0

Table 2-2. SPSR

Digit	7	6	5	4	3	2	1	0
Flag	**SPIF**	**WCOL**	**-**	**-**	**-**	**-**	**-**	**SPI2X**
Read/Write	R	R	R	R	R	R	R	R/W
Init. value	0	0	0	0	0	0	0	0

SPI registers

- SPIE: SPI interrupt enable. If in SPI status register the SPIF flag is set, then setting this bit (SPIE=1) will bring to SPI interruption processing.
- SPE: SPI enable. If this flag is set, SPI is enabled. This bit should be set if SPI must be used regardless of the mode.

- DORD: Data shift order. If DORD=1, transmission is processed in LSB format. In opposite case (DORD=0), MSB is sent first.
- MSTR: Master/slave selection. If the MSTR flag is set (MSTR=1), SPI serves as master, in other case (MSTR=0), it serves as slave. If SS is set as input and it had low level, when MSTR was 1, the MSTF bit is cleared automatically and SPIF flag (interrupt) is set to 1 in SPSR register. To set SPI to master mode, user should provide programmatic installation of MSTR bit.
- CPOL: synchronization polarity. If CPOL=1, SCK has high level in waiting mode. If CPOL=0, SCK has low level in waiting mode.
- CPHA: Synchronization phase. The value of this bit defines SCK edge (rising or falling), through which data acquisition is done.
- SPR1, SPR0: SPI synchronization frequency selection bits (1 and 0). These bits together with SPI2X flag, which is set in status register, set the synchronization frequency on SCK in master mode. SPR1 and SPR0 do not have any effect in slave mode. The connection between SCK frequency and synchronization generator (fosc) frequency is given below:

Table 2-3. SCK frequency

SPI2X	SPR1	SPR0	SCK frequency
0	0	0	fosc/4
0	0	1	fosc/16
0	1	0	fosc/64
0	1	1	fosc/128
1	0	0	fosc/2
1	0	1	fosc/8
1	1	0	fosc/32
1	1	1	fosc/64

- SPIF: SPI interrupt flag. This flag is set when serial transmission is over. Interrupt is generated if SPIE bit is set in SPI control register and general interruptions are allowed. If SS is configured as input and it has low signal level, than if SPI is in master mode, the SPIF flag will be set. SPIF is cleared through hardware when shifting to corresponding interrupt vector. Alternatively, SPIF bit is cleared during first read of SPI Status Register with set SPIF flag (SPIF=1), also during SPI Data Register (SPDR) access.
- WCOL: Write collision flag. This is read only bit. This bit is set if the SPDR register is written during a data transfer. The WCOL bit (as well as SPIF bit) is cleared by first reading the SPI Status Register with WCOL set, and then accessing the SPI Data register.
- SPI2X: Double SPI speed. When this bit is set to 1, the SPI speed will be doubled if the SPI is in master mode. If SPI is in slave mode, SPI guaranteed speed is fosc/4 and less.

There is a separate register in SPI for data (SPDR) (Table 2-4). SPI data register has access to read and write and is intended for data transfer between register file and SPI shift register. Writing to this register initiates data transfer. When reading from this register, it is actually the receive buffer of shift register, from which data is read.

Table 2-4 SPI data register

Digit	7	6	5	4	3	2	1	0
	MSB							**LSB**
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W
Init. value	x	x	x	x	x	x	x	x

Transmission modes

SPI has 4 transmission modes, which are based on clock polarity (CPOL) and clock phase (CPHA) combinations. CPOL is the level on tact line before starting and after finishing the transmission: low (0) or high (1). And the phase defines the edge of the signal (rise or fall) on which bits are transmitted.

- Mode 0: CPOL=0, CPHA=0. The bit is read on clock signal rise (0 -> 1) and it is written on fall (1 ->0).
- Mode 1: CPOL=0, CPHA=1. Read — on fall, write — on rise.
- Mode 2: CPOL=1, CPHA=0. Read — on fall, write — on rise.
- Mode 3: CPOL=1, CPHA=1. Read — on rise, write — on fall.

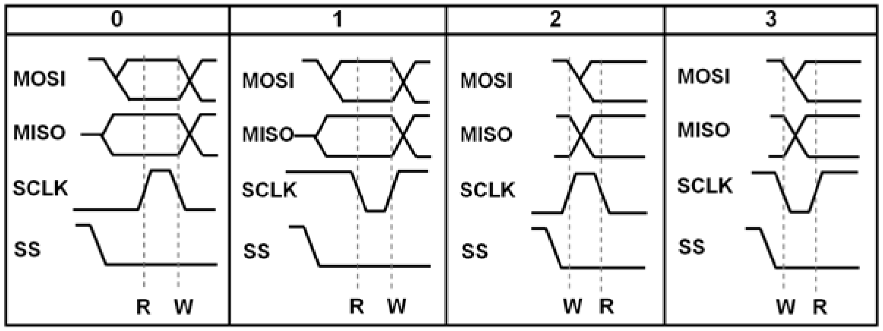
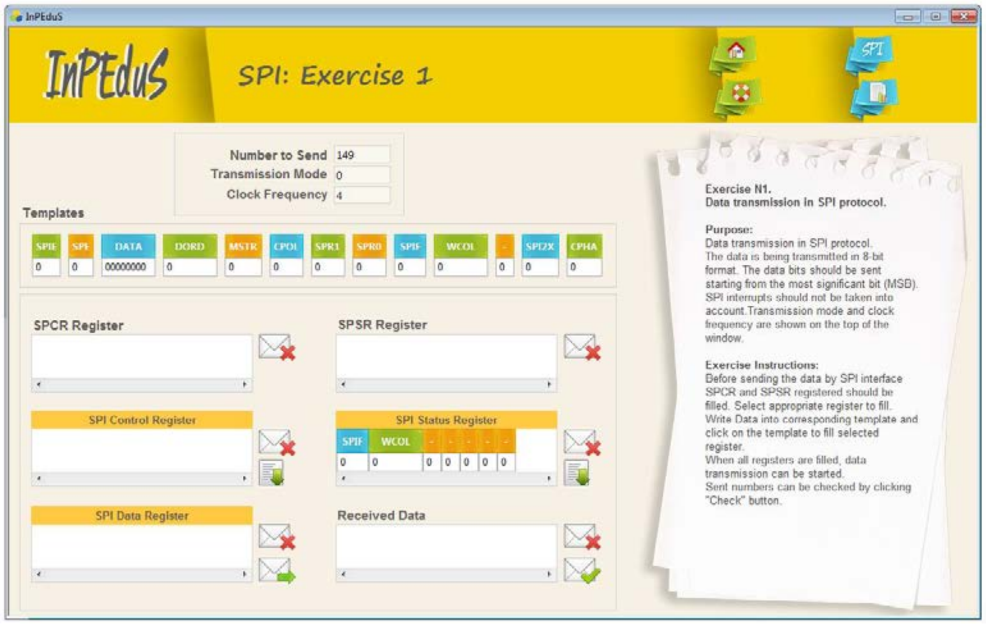


Figure 2-3 SPI Transmission modes

SPI data can be transmitted both in MSB and LSB formats. Usually the first format is used, but it should be clarified in documentation before starting to work with device.

Exercise №1. Data transmission in SPI protocol.

The purpose of the exercise is a study of data transmission in SPI protocol.



Number to Send 149
Transmission Mode 0
Clock Frequency 4

Exercise N1.
Data transmission in SPI protocol.

Purpose:
Data transmission in SPI protocol.
The data is being transmitted in 8-bit format. The data bits should be sent starting from the most significant bit (MSB). SPI interrupts should not be taken into account.Transmission mode and clock frequency are shown on the top of the window.

Exercise Instructions:
Before sending the data by SPI interface SPCR and SPSR registered should be filled. Select appropriate register to fill.
Write Data into corresponding template and click on the template to fill selected register.
When all registers are filled, data transmission can be started.
Sent numbers can be checked by clicking "Check" button.

The data is being transmitted in 8-bit format. The data bits should be sent starting from the most significant bit (MSB). SPI interrupts should not be taken into account.

The program generates numbers to be sent automatically. These numbers are given in the **“Numbers to Send”** field on the top of the window.

Transmission mode and clock frequency are shown on the top of the window.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding template and click on the template to construct the frame to be sent.

Before sending the data by SPI interface SPCR and SPSR registered should be filled. Select **“SPI Control Register”** to fill SPCR register. After clicking selected template will appear in the selected field. After the frame is complete click the **“Load”** button. If the frame is constructed correctly, it will appear in the **“SPCR Register”** field.

Select **“SPI Status Register”** to fill SPSR register. After clicking selected template will appear in the selected field. After the frame is complete click the **“Load”** button. If the frame is constructed correctly, it will appear in the **“SPSR Register”** field.

In case of error within the frame Warning Indicator will turn red. Click the **“Clear”** button and assemble the frame once more.

After SPCR and SPSR registers are filled data transmission can be started.

Select **“SPI Data Register”** and click on the data template. After clicking selected template will appear in the selected field.

Sent numbers can be checked by clicking **“Check”** button. If the numbers within the frame are correct, the dialog box will appear with “Correct!” text, the dialog with “Incorrect!” text will appear in opposite case. Clear all fields in this case and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **“Report”** button to create the report.

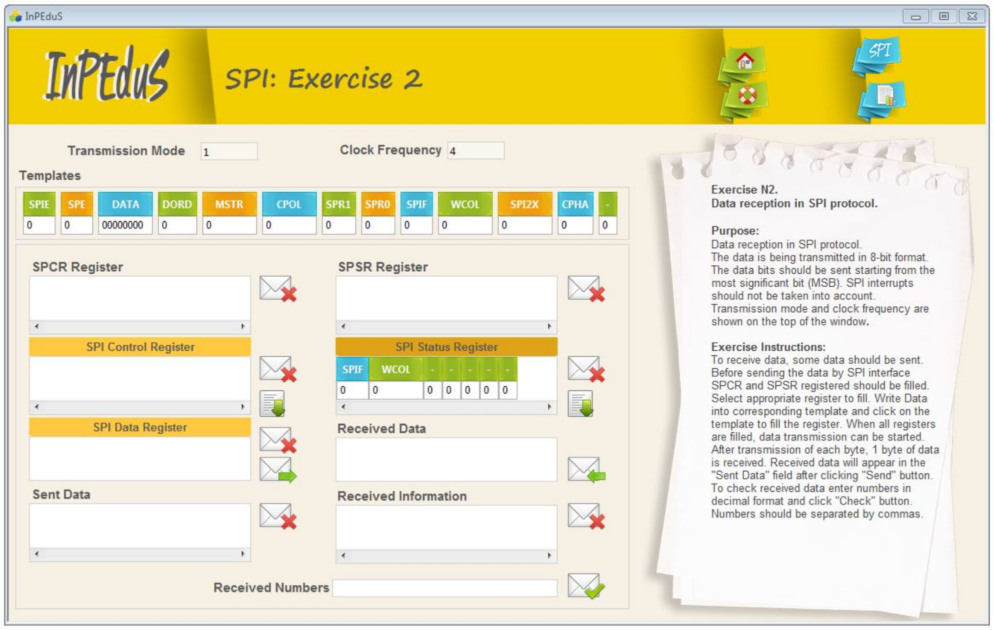
If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

Exercise №2. Data reception in SPI protocol.

The purpose of the exercise is a study of data reception in SPI protocol.



Transmission Mode 1

Clock Frequency 4

SPIE	SPE	DATA	DORD	MSTR	CPOL	SPR1	SPR0	SPIF	WCOL	SPI2X	CPHA	-
0	0	00000000	0	0	0	0	0	0	0	0	0	0

SPIF	WCOL	-	-	-	-	-
0	0	0	0	0	0	0

Exercise N2.
Data reception in SPI protocol.

Purpose:
Data reception in SPI protocol.
The data is being transmitted in 8-bit format.
The data bits should be sent starting from the most significant bit (MSB). SPI interrupts should not be taken into account.
Transmission mode and clock frequency are shown on the top of the window.

Exercise Instructions:
To receive data, some data should be sent. Before sending the data by SPI interface SPCR and SPSR registered should be filled. Select appropriate register to fill. Write Data into corresponding template and click on the template to fill the register. When all registers are filled, data transmission can be started. After transmission of each byte, 1 byte of data is received. Received data will appear in the "Sent Data" field after clicking "Send" button. To check received data enter numbers in decimal format and click "Check" button. Numbers should be separated by commas.

The data is being transmitted in 8-bit format. The data bits should be sent starting from the most significant bit (MSB). SPI interrupts should not be taken into account.

Transmission mode and clock frequency are shown on the top of the window.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding template and click on the template to construct the frame to be sent.

Before receiving the data by SPI interface SPCR and SPSR registered should be filled. Select **"SPI Control Register"** to fill SPCR register. After clicking selected template will appear in the selected field. After the frame is complete click the **"Load"** button. If the frame is constructed correctly, it will appear in the **"SPCR Register"** field.

Select **"SPI Status Register"** to fill SPSR register. After clicking selected template will appear in the selected field. After the frame is complete click the **"Load"** button. If the frame is constructed correctly, it will appear in the **"SPSR Register"** field.

In case of error within the frame Warning Indicator will turn red. Click the **"Clear"** button and assemble the frame once more.

To receive the data, any data should be sent. To send the data select **"SPI Data Register"** and click on the data template. After clicking selected template will appear in the selected field.

If there are no any errors in the filled registers, data will appear in the **“Sent Data”** field after clicking **“Send”** button.

Click the **“Receive”** button to receive the data. Data is shown in binary format. To check received data convert binary numbers to decimal, enter numbers and click **“Check”** button. If the numbers within the frame are correct, the dialog box will appear with “Correct!” text, the dialog with “Incorrect!” text will appear in opposite case.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **“Report”** button to create the report.

If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

3. Protocol I2C

I2C (Inter - Integrated Circuit) is a serial interface intended for data transmission between integral circuits. It was developed by Philips in the early 1980s as a simple bus for interconnections between electronic devices. The protocol is used to connect low-speed peripheral components to motherboard, to get data from different sensors, to create connections between different components of integrated systems, etc.

- Physically I2C is a combination of two bidirectional lines, which are Serial Data Line – SDA and Serial Clock Input SC, which are pulled up with resistors. The circuit design is given in Figure 3-1.

Any element that is initiating transfer is master, and any addressed element is a slave. In systems with several masters the same element can be used both as a master and as a slave.

When the bus is free, both the lines are in state “1”. Data can be transferred in I2C protocol with up to 100 kbit/s speed in standard mode, or with up to 400 kbit/s in high speed mode. The number of connected interfaces dependents only on the bus capacitance, which maximal value is 400 pF.

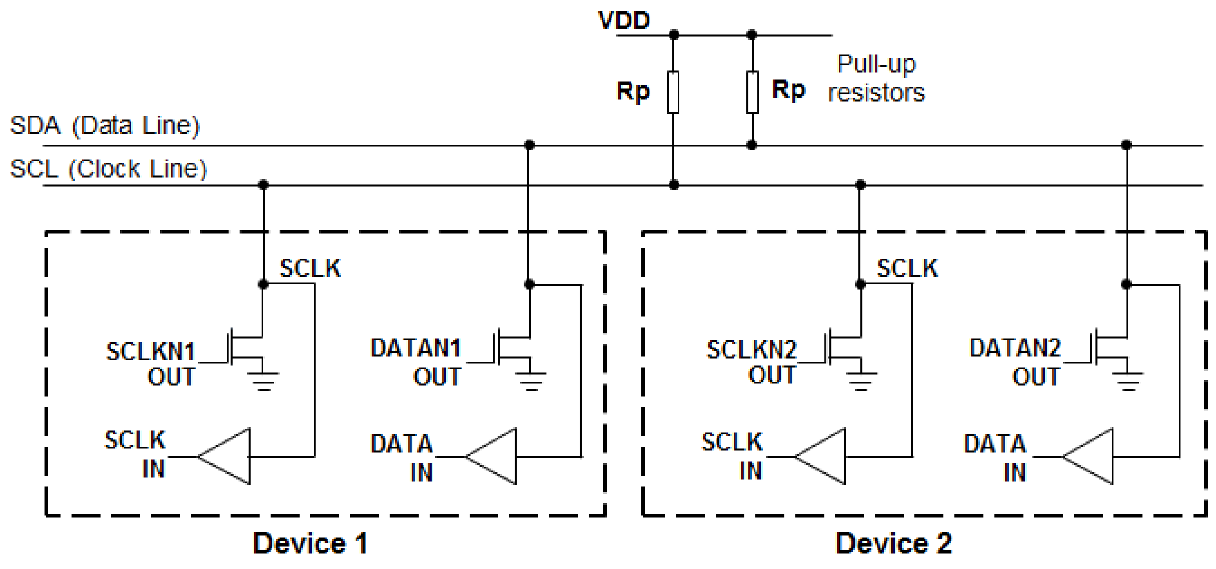


Figure 3-1 I2C device connections

There are two special states of I2C bus: START and STOP, which serve to indicate start and finish of transmission and shift of bus state to inactive, correspondingly. It should be noted that before setting the START state, signals on SDA and SCL lines can be arbitrary (Figure 3-2).

START state – shifts SDA line from “1” to “0” if the state of SCL is “1”.

STOP state – shifts SDA line from “0” to “1” if the state of SCL is “1”.

These two states are always generated by master.

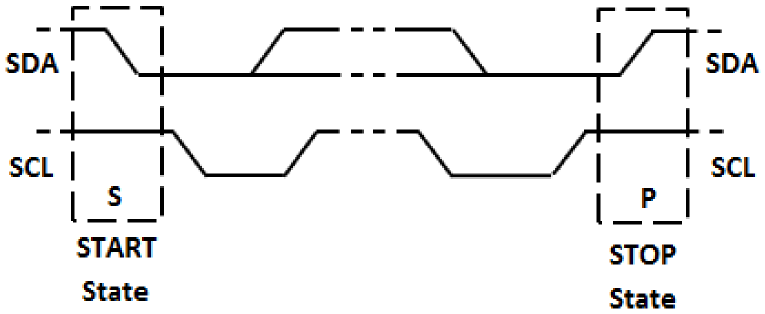


Figure 3-2 START and STOP states

As the bus lines are pulled to power supply, the devices should pull down lines to ground to send “0”, and release them to send “1”. Connection for cooperative work of devices with this kind of inclusion is called wired AND.

Transfers are done byte wise. Number of bytes to be sent during single transmission is not limited. Each byte should be accompanied with acknowledgement bit ACK (ACKnowledge). Data is transmitted started from Most Significant Bit (MSB) (Figure 3-3). If the receiver is not able to receive the full byte of information, it is giving ACK signal, which is used by transmitter to synchronize and signalize the receiver fault (or absence).

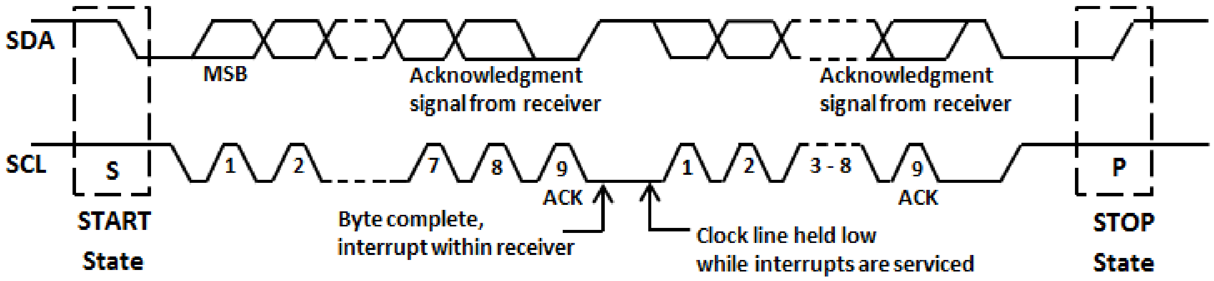


Figure 3-3 Data transmission through I2C bus

Transmitter sets the SDA line to “1” during synchronization pulse to confirm the transfer. In this case the receiver should set “0” on SDA (Figure 3-4).

If the slave receiver does not confirm the slave address (NACK), the SDA data line should remain “1”. Master can give STOP signal after this and repeat the transmission.

If the slave receiver confirms the slave address, but, after some time, it is not able to receive data bytes, master should stop the transmission. During reception of the last byte in the sequence master can give STOP state instead of signal. In this case the slave receiver should free the data line.

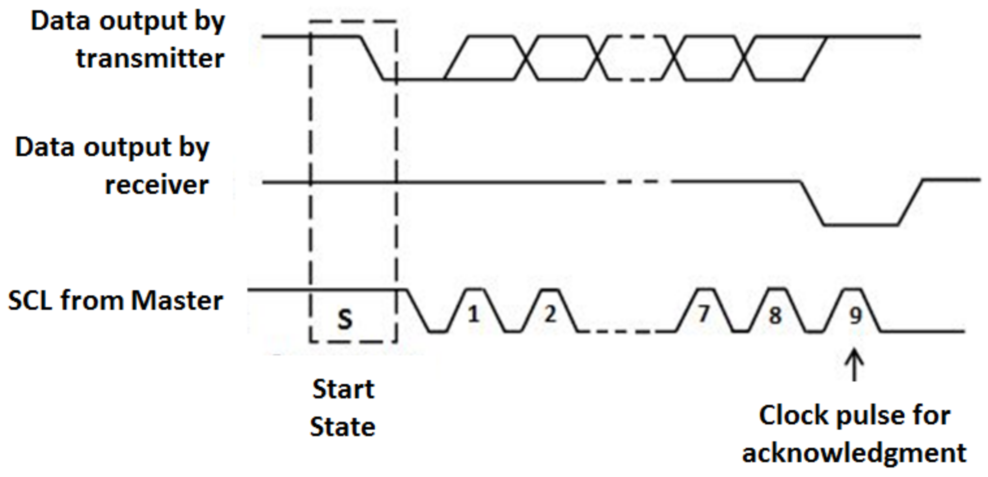


Figure 3-4 Transfer confirmation

Transmission with 7-bit addressing is given in Figure 3-5. The transmission of address byte follows the START state, wherein 8th byte of the address defines the direction of data transfer (“0” – write, “1” - read). Data transmission always ends by STOP state generation from master.

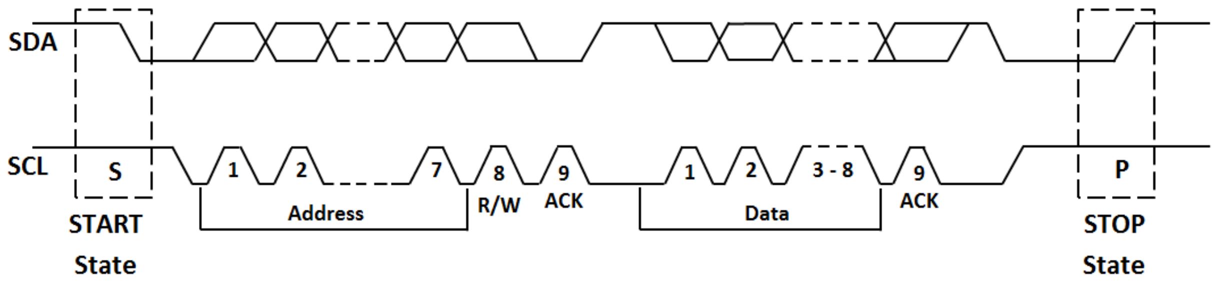


Figure 3-5 I2C data transmission

Examples of data transfer from master to slave as well as data reading by master from slave are given below (Figure 3-6 and Figure 3-7).

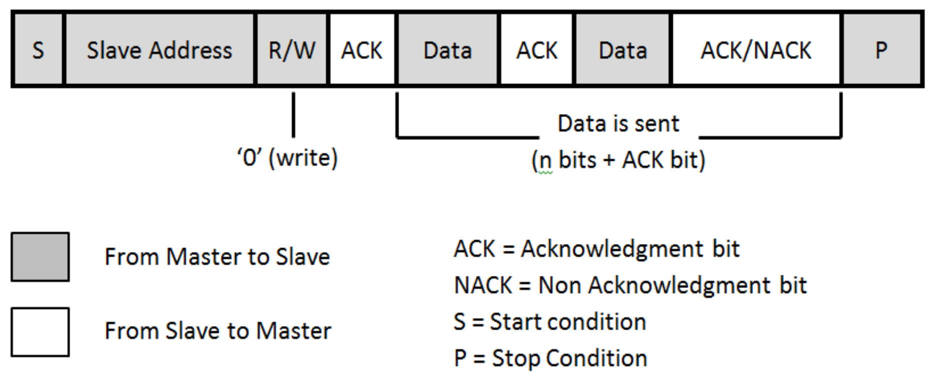


Figure 3-6 Data transmission from master to slave

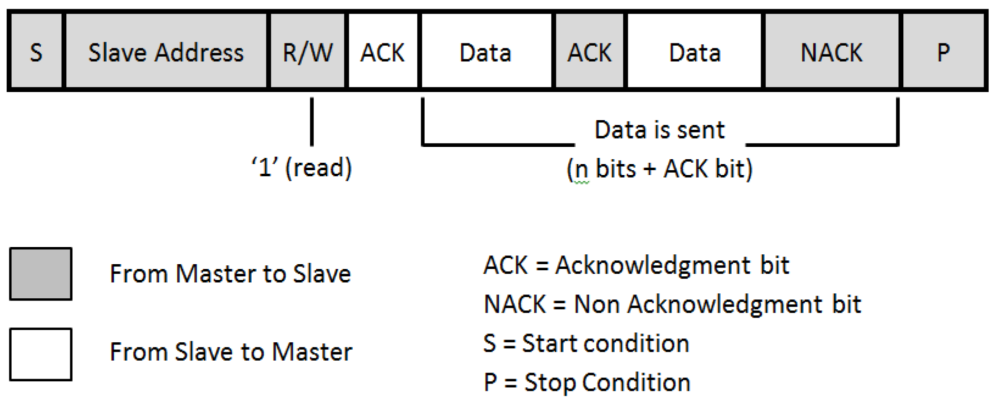
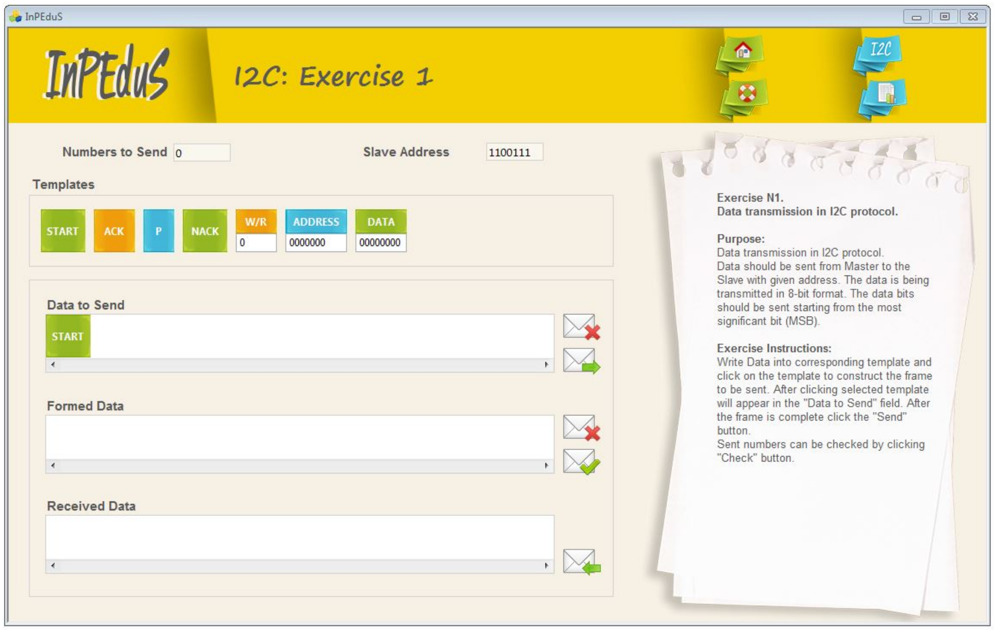


Figure 3-7 Reading data by master

Exercise №1. Data transmission in I2C protocol.

The purpose of the exercise is a study of data transmission in I2C protocol.



Numbers to Send 0

Slave Address 1100111

W/R 0

ADDRESS 0000000

DATA 00000000

Exercise N1.
Data transmission in I2C protocol.

Purpose:
Data transmission in I2C protocol.
Data should be sent from Master to the Slave with given address. The data is being transmitted in 8-bit format. The data bits should be sent starting from the most significant bit (MSB).

Exercise Instructions:
Write Data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the "Data to Send" field. After the frame is complete click the "Send" button.
Sent numbers can be checked by clicking "Check" button.

Data should be sent from Master to the Slave with given address. The data is being transmitted in 8-bit format. The data bits should be sent starting from the most significant bit (MSB).

The program generates numbers to be sent automatically. These numbers are given in the **"Numbers to Send"** field on the top of the window.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the **"Data to Send"** field. After the frame is complete click the **"Send"** button.

Before sending the data to the slave Start bit, slave address and write/read bit should be sent.

In case of error within the frame Warning Indicator will turn red. Click the **"Clear"** button and assemble the frame once more.

If the frame is constructed correctly, it will appear in the **"Formed Data"** field after clicking **"Send"** button, and in the field **"Received Data"** Acknowledgement bit will appear. Click **"Receive"** button to receive the Acknowledgement. Acknowledgement will appear in the **"Formed Data"** field and data to be sent will be shown in the **"Data to Send"** field.

To stop the data transmission, send stop bit.

Sent numbers can be checked by clicking **“Check”** button. If the numbers within the frame are correct, the dialog box will appear with “Correct!” text, the dialog with “Incorrect!” text will appear in opposite case. Clear **“Formed Data”** field in this case and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **“Report”** button to create the report.

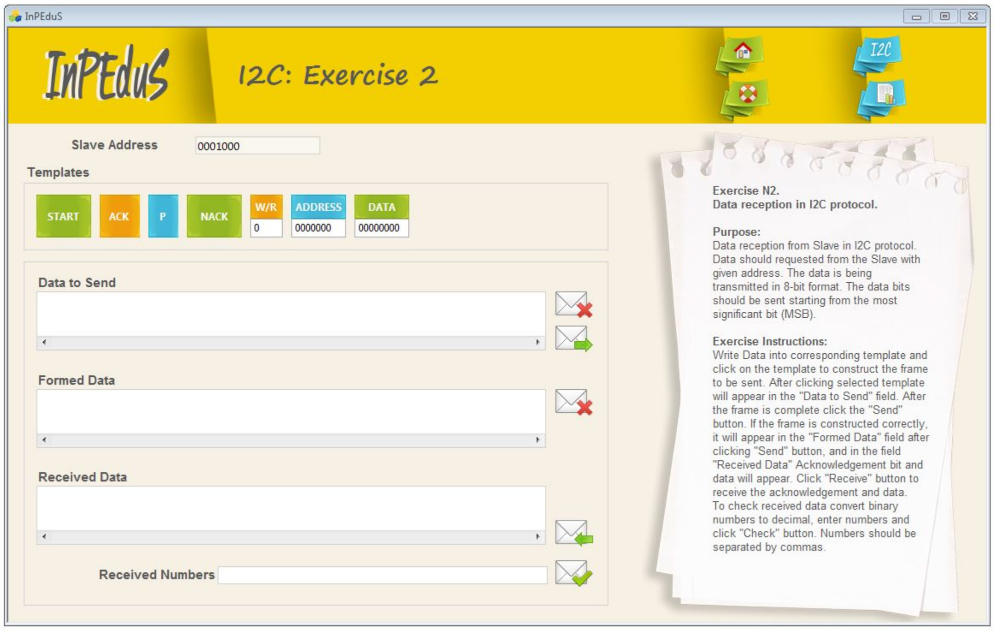
If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

Exercise №2. Data reception in I2C protocol.

The purpose of the exercise is a study of data reception in I2C protocol.



Exercise N2.
Data reception in I2C protocol.

Purpose:
Data reception from Slave in I2C protocol. Data should requested from the Slave with given address. The data is being transmitted in 8-bit format. The data bits should be sent starting from the most significant bit (MSB).

Exercise Instructions:
Write Data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the "Data to Send" field. After the frame is complete click the "Send" button. If the frame is constructed correctly, it will appear in the "Formed Data" field after clicking "Send" button, and in the field "Received Data" Acknowledgement bit and data will appear. Click "Receive" button to receive the acknowledgement and data.
To check received data convert binary numbers to decimal, enter numbers and click "Check" button. Numbers should be separated by commas.

Data should be sent from the Slave with given address to the Master. The data is being transmitted in 8-bit format. The data bits should be sent starting from the most significant bit (MSB).

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the **"Data to Send"** field. After the frame is complete click the **"Send"** button.

Before sending data request to the Slave, Start bit, slave address and write/read bit should be sent.

In case of error within the frame Warning Indicator will turn red. Click the **"Clear"** button and assemble the frame once more.

If the frame is constructed correctly, it will appear in the **"Formed Data"** field after clicking **"Send"** button, and in the field **"Received Data"** Acknowledgement bit and data will appear. Click **"Receive"** button to receive the acknowledgement and data. Acknowledgement and data will appear in the **"Formed Data"** field.

To stop the data transmission, send stop bit.

To check received data convert binary numbers to decimal, enter numbers and click **"Check"** button. If the numbers within the frame are correct, the dialog box will appear with "Correct!" text, the dialog with "Incorrect!" text will appear in opposite case.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **“Report”** button to create the report.

If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

4. Protocol RS232

RS-232 (Recommended Standard) is a popular protocol, which is used for communication between computer and modems and other peripheral devices. Standard RS-232 was introduced in 1962.

Equipment connected through RS-232 protocol can be divided into 2 types: DCE (Data Communication Equipment) и DTE (Data Terminal Equipment).

With RS-232 protocol information between 2 devices can be transferred in distances up to 20m, as during data transmission through cable signals are weakened and distorted. To guarantee higher signal sustainability to noises during transmission, higher signal levels are used than standard 5V.

Two signal levels are used in RS-232: logical 1 (mark) and 0 (space). Negative voltage level corresponds to logical 1, and the positive to logical 0. Voltage values used in this protocol are given in Table 4-1 and Table 4-2.

Table 4-1. Data signal levels

Level	Transmitter	Receiver
Logical 0	From +5V to +15V	From +3V to +25V
Logical 1	From -5V to -15V	From -3V to -25V
Undefined	From -3V to +3V	

Table 4-2. Command signal levels

Signal	Driver	Terminator
"Off"	From -5V to -15V	From -3V to -25V
"On"	From 5V to 15V	From 3V to 25V

Maximal cable length dependence on information transmission speed is given below:

Table 4-3. Cable length depending on transmission speed

Speed [baud]	Max length [foot]	Max length [meters]
19 200	50	15
9 600	500	150
4 800	1000	300
2 400	3000	900

Transmission speed in RS-232 is measured in bauds (bit/sec). Maximal speed defined in standard is 20000 bauds. However nowadays devices can work considerably faster.

Devices are connected through cables with 9 or 25 pin D type connectors. Usually they are denoted as DB-9, CANNON 9, CANNON 25, etc. Each pin is denoted and numerated. DB-9 type connector is shown in Figure 4-1.

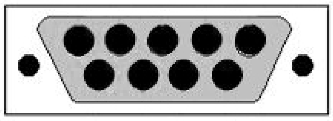


Figure 4-1 DB-9 type connector

DB-9 connector pinout is given in Table 4-4.

Table 4-4. DB-9 Connector pinout

Contact	Abbreviation	Direction	Name
1	DCD	In	Data Carrier Detect
2	RXD	In	Received Data
3	TXD	Out	Transmitted Data
4	DTR	Out	Data Terminal Ready
5	GND	---	Ground
6	DSR	In	Data Set Ready
7	RTS	Out	Request To Send
8	CTS	In	Clear To Send
9	RI	In	Ring Indicator

Parity Control

For parity check, two connected devices should calculate parity bits with the same algorithm (even or odd parity). In case of even parity, data bits (including the parity bit) should have even number of logical “1”. Odd parity corresponds to opposite case.

Parity check is the simplest way of error checking. It can detect error in one bit, but in case of errors in 2 bits simultaneously this checking cannot detect errors. Besides, this control does not define which bit has the error.

Other mechanisms of error checking are inclusion of start and stop bits into transmission, CRC, etc.

The signal line has two states: On and Off (logical 1 or 0). Line in waiting state is always on. When device or computer wants to transfer data, they set the line in Off state, as a start bit setting.

Stop bit allows device or computer to process synchronization in case of failures. For example, noise on line can hide start bit. Duration between start and stop bits is constant and depends on transfer speed, number of data bits within message and parity bit existence. Stop bit is always on. If receiver detects off state when stop bit should be present, error is detected.

In the frame stop signal can have 1 or 2 bits. 1 bit selection is more common.

Example

Data structure with synchronization clock signal is given on Figure 4-2. Eight data bits, parity bit and stop bit are used in this example. This structure is also denoted as 8E1.

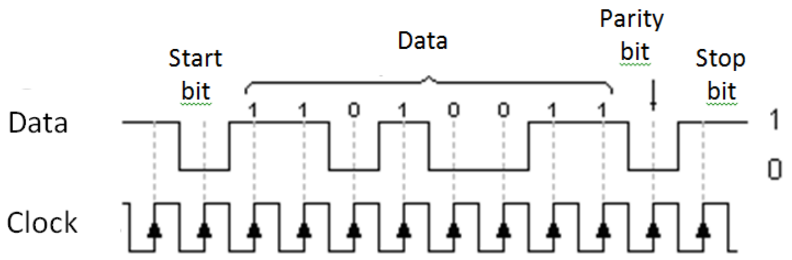
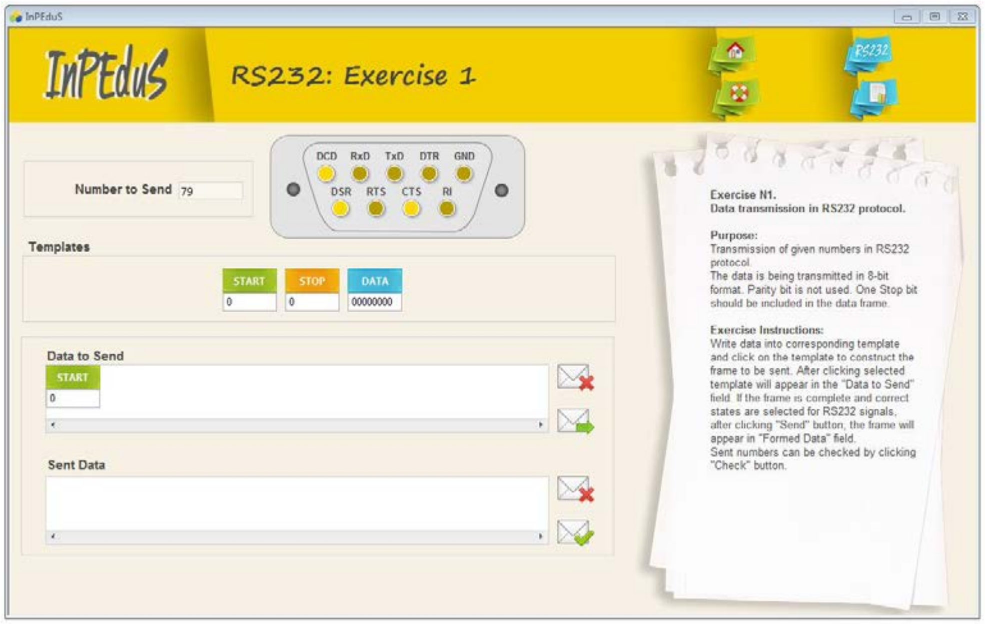


Figure 4-2 Timing diagram

Exercise №1. Data transmission in RS232 protocol.

The purpose of the exercise is a study of data transmission in RS232 protocol.



Exercise N1.
Data transmission in RS232 protocol.

Purpose:
Transmission of given numbers in RS232 protocol.
The data is being transmitted in 8-bit format. Parity bit is not used. One Stop bit should be included in the data frame.

Exercise Instructions:
Write data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the "Data to Send" field. If the frame is complete and correct states are selected for RS232 signals, after clicking "Send" button, the frame will appear in "Formed Data" field.
Sent numbers can be checked by clicking "Check" button.

The data is being transmitted in 8-bit format. Parity bit should not be included in the data frame. Frame should have 1 stop bit.

The program generates numbers to be sent automatically. These numbers are given in the **"Numbers to Send"** field on the top of the window.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the **"Data to Send"** field. After the frame is complete and correct states for the RS232 signals are set click the **"Send"** button.

In case of error within the frame or signals' states Warning Indicator will turn red. Click the **"Clear"** button and assemble the frame once more.

If the frame is constructed correctly, it will appear in the **"Sent Data"** field after clicking **"Send"** button.

Sent numbers can be checked by clicking **"Check"** button. If the numbers within the frame are correct, the dialog box will appear with "Correct!" text, the dialog with "Incorrect!" text will appear in opposite case. Clear **"Sent Data"** field in this case and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **"Report"** button to create the report.

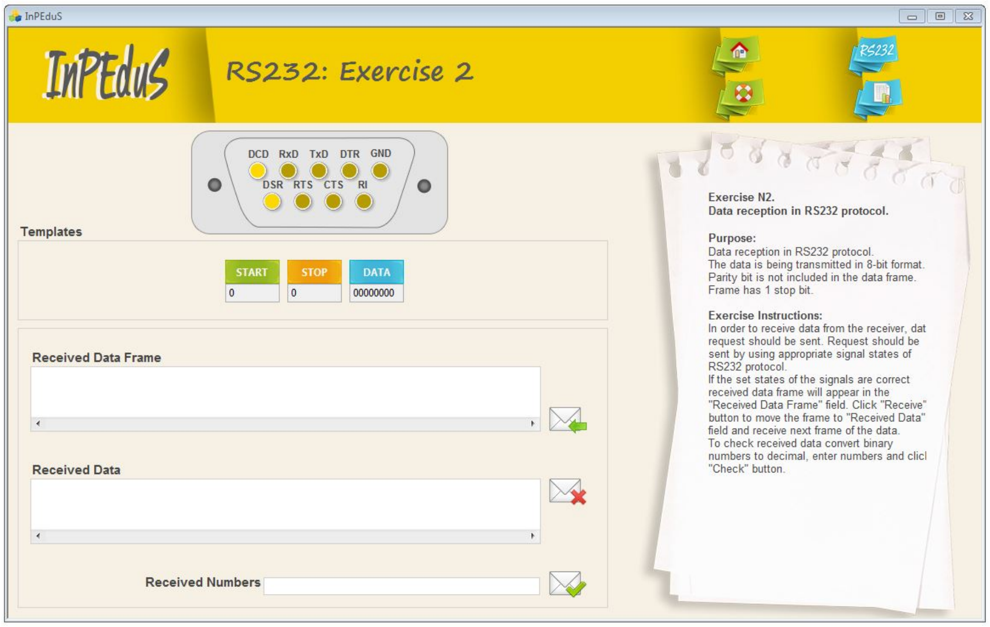
If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

Exercise №2. Data reception in RS232 protocol.

The purpose of the exercise is a study of data reception in RS232 protocol.



Exercise N2.
Data reception in RS232 protocol.

Purpose:
Data reception in RS232 protocol.
The data is being transmitted in 8-bit format.
Parity bit is not included in the data frame.
Frame has 1 stop bit.

Exercise Instructions:
In order to receive data from the receiver, dat
request should be sent. Request should be
sent by using appropriate signal states of
RS232 protocol.
If the set states of the signals are correct
received data frame will appear in the
"Received Data Frame" field. Click "Receive"
button to move the frame to "Received Data"
field and receive next frame of the data.
To check received data convert binary
numbers to decimal, enter numbers and clicl
"Check" button.

The data is being transmitted in 8-bit format. Parity bit is not included in the data frame. Frame has 1 stop bit.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

In order to receive data from the receiver, data request should be sent. Request should be sent by using appropriate signal states of RS232 protocol.

If the set states of the signals are correct received data frame will appear in the **"Received Data Frame"** field. Click **"Receive"** button to move the frame to **"Received Data"** field and receive next frame of the data.

In case of error within the signals' states Warning Indicator will turn red. Correct signal's states and click the **"Receive"** button once more.

To check received data convert binary numbers to decimal, enter numbers and click **"Check"** button. If the numbers within the frame are correct, the dialog box will appear with "Correct!" text, the dialog with "Incorrect!" text will appear in opposite case.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **"Report"** button to create the report.

If the exercise is not finished after **"Report"** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

5. Protocol RS485/422

RS-485 and **RS-422** interfaces are the most popular standards of physical level connection.

Standard RS-485 was designed by 2 companies: EIA — Electronics Industries Association and TIA — Telecommunications Industry Association.

RS-422 is American standard, the international equivalent of which is ITU-T Recommendation V.11.

RS-485/422 networks represent transmitters/receivers which are connected through twisted pair. The basis of RS-485/422 interfaces is the principle of differential (balanced) data transmission. This kind of transmission guarantees high stability to in phase noise. In phase noise is the noise which affects both wires of the line identically.

Transmitter must guarantee 1.5V signal level for maximal load and not more than 6V in idle mode. Voltage levels are measured differentially. The received signal level should be not less than 200mV.

Maximal connection speed in RS-485/422 specification can reach 10 Mbaud. Maximal distance is 1200 m. If the distance should be more than 1200 m or more devices should be connected, special repeaters are used.

RS-485 standard allows only 32 transmitter/receiver pairs, however the manufacturers have expanded the opportunities of RS-485, so now it can support from 128 to 255 devices on one line, and by using repeater the number of devices practically have no limitations. In RS-485 it is possible and in case of long wires it is necessary to use terminators, which are embedded to device with RS-485 protocol (although in case of short wires it is possible that the signal will be weakened by using terminators). RS-485 standard also allows the use of shielded twisted pair cable (2-wire RS-485). It is also possible to use 4-wire twisted pair (4-wire RS-485). In this case it is possible to get full duplex transmission. In this case one of the devices should serve as Master and others as Slaves. Communication is done only between Master and Slaves, no data is transferred between slaves. In these cases the RS-422 driver usually serves as master, and RS-485 devices as slaves, for system cheapening purposes. RS-422 standard initially considers the use of 4-wire shielded twisted pair cable, but allows connections only from one device to others (up to 5 drivers and up to 10 receivers for each driver).

RS-422 is full duplex interface. Reception and transmission are processed through two separate wire pairs. On each pair only one transmitter is allowed.

RS-485 is half-duplex interface. Reception and transmission are done through one pair with time delay. Multiple transmitters can exist within the network, as they can turn off in receiver mode.

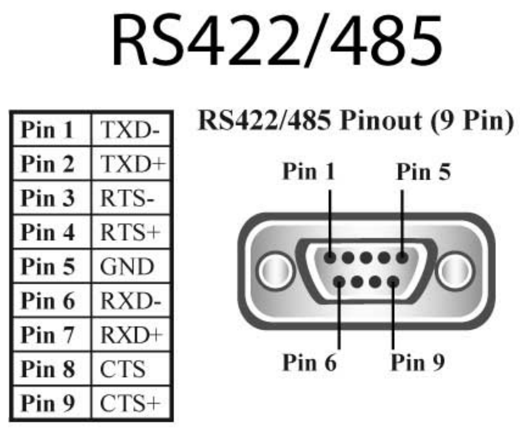
Basic technical parameters of RS-485/422 protocols are given in Table 5-1.

Table 5-1 Basic technical parameters

Interface parameters	RS-422	RS-485
Allowed transmitter/receiver number	1 / 10	32 / 32
Maximal cable length	1200 m	1200 m
Maximal speed	10 Mb/sec	10 Mb/sec
Transmitter Voltage range for "1"	+2...+10V	+1.5...+6V
Transmitter Voltage range for "0"	-2...-10V	-1.5...-6V
Transmitter in phase voltage range	-3...+3V	-1...+3V
Allowed receiver Voltage range	-7...+7V	-7...+12V
Receiver sensitivity threshold range	±200 mV	±200 mV
Maximum short-circuit current of driver	150 mA	250 mA
Transmitter allowed load resistance	100 Ohm	54 Ohm
Receiver input resistance	4 kOhm	12kOhm
Transmitter maximum rise time	10% bits	30% bits

RS-422 uses two (or more) strictly separated wire pairs: one for reception, one for transmission, and one wire for each control/handshake signal.

Devices are connected through cables with 9 or 25 pin D type connectors. Usually they are denoted as DB-9, CANNON 9, CANNON 25, etc. Each pin is denoted and numerated. DB-9 type connector is shown in Figure 5-1.



Pin 1	TXD-
Pin 2	TXD+
Pin 3	RTS-
Pin 4	RTS+
Pin 5	GND
Pin 6	RXD-
Pin 7	RXD+
Pin 8	CTS
Pin 9	CTS+

Figure 5-1 DB-9 connector

In the Table 5-2. Connector pinout is presented with short description of the pins.

Table 5-2 Connector pin outs

Contact	Abbreviation	Direction	Name
1	TXD-	Out	Transmitted Data
2	TXD+	Out	Transmitted Data
3	RTS-	Out	Request to Send
4	RTS+	Out	Request to Send
5	GND	---	Ground
6	RXD-	In	Received Data
7	RXD+	In	Received Data
8	CTS-	In	Clear to Send
9	CTS+	In	Clear to Send

Data structure transmitted with RS485/422 protocol is identical to RS232 protocol. Data structure with synchronization clock signal is given on Figure 5-2. Eight data bits, parity bit and stop bit are used in this example. This structure is also denoted as 8E1.

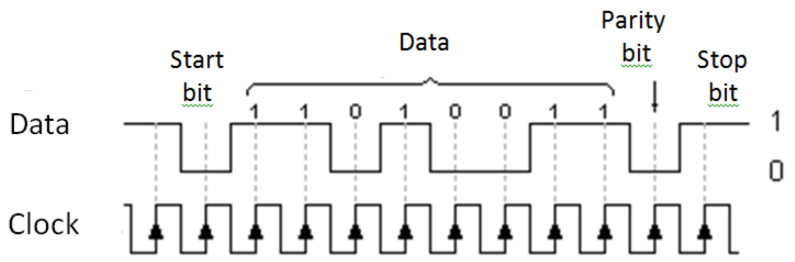


Figure 5-2 Time diagram

Parity Control

For parity check, two connected devices should calculate parity bits with the same algorithm (even or odd parity). In case of even parity, data bits (including the parity bit) should have even number of logical “1”. Odd parity corresponds to opposite case.

Parity check is the simplest way of error checking. It can detect error in one bit, but in case of errors in 2 bits simultaneously this checking cannot detect errors. Besides, this control does not define which bit has the error.

Other mechanisms of error checking are inclusion of start and stop bits into transmission, CRC, etc.

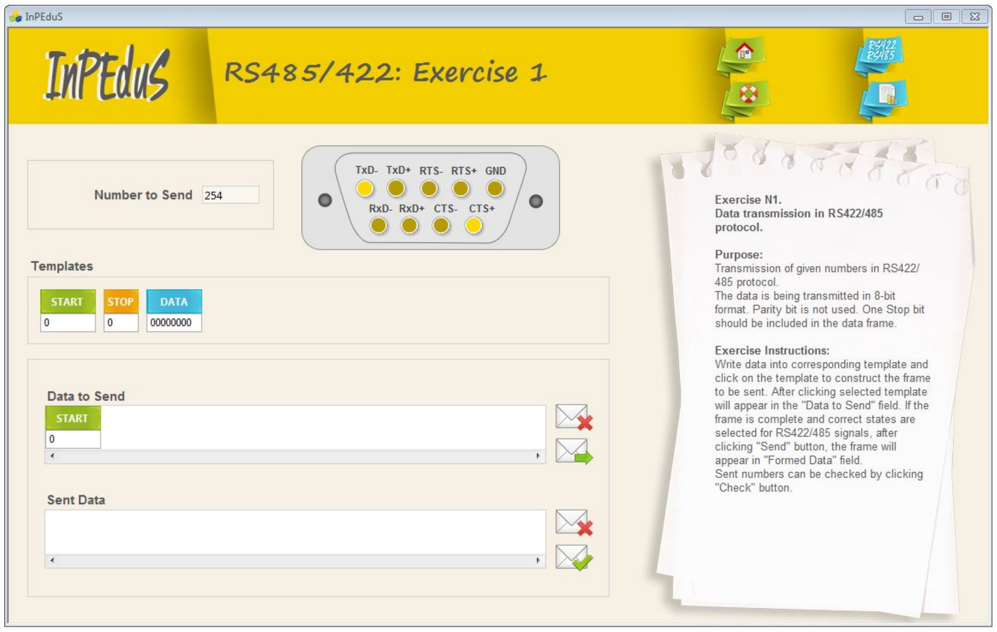
The signal line has two states: On and Off (logical 1 or 0). Line in waiting state is always on. When device or computer wants to transfer data, they set the line in Off state, as a start bit setting.

Stop bit allows device or computer to process synchronization in case of failures. For example, noise on line can hide start bit. Duration between start and stop bits is constant and depends on transfer speed, number of data bits within message and parity bit existence. Stop bit is always on. If receiver detects off state when stop bit should be present, error is detected.

In the frame stop signal can have 1 or 2 bits. 1 bit selection is more common.

Exercise №1. Data transmission in RS422/485 protocol.

The purpose of the exercise is a study of data transmission in RS422/485 protocol.



Number to Send: 254

Templates: START 0, STOP 0, DATA 00000000

Data to Send: START 0

Exercise N1.
Data transmission in RS422/485 protocol.

Purpose:
Transmission of given numbers in RS422/485 protocol.
The data is being transmitted in 8-bit format. Parity bit is not used. One Stop bit should be included in the data frame.

Exercise Instructions:
Write data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the "Data to Send" field. If the frame is complete and correct states are selected for RS422/485 signals, after clicking "Send" button, the frame will appear in "Formed Data" field.
Sent numbers can be checked by clicking "Check" button.

The data is being transmitted in 8-bit format. Parity bit should not be included in the data frame. Frame should have 1 stop bit.

The program generates numbers to be sent automatically. These numbers are given in the **"Numbers to Send"** field on the top of the window.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the **"Data to Send"** field. After the frame is complete and correct states for the RS422/485 signals are set click the **"Send"** button.

In case of error within the frame or signals' states Warning Indicator will turn red. Click the **"Clear"** button and assemble the frame once more.

If the frame is constructed correctly, it will appear in the **"Sent Data"** field after clicking **"Send"** button.

Sent numbers can be checked by clicking **"Check"** button. If the numbers within the frame are correct, the dialog box will appear with "Correct!" text, the dialog with "Incorrect!" text will appear in opposite case. Clear **"Sent Data"** field in this case and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **"Report"** button to create the report.

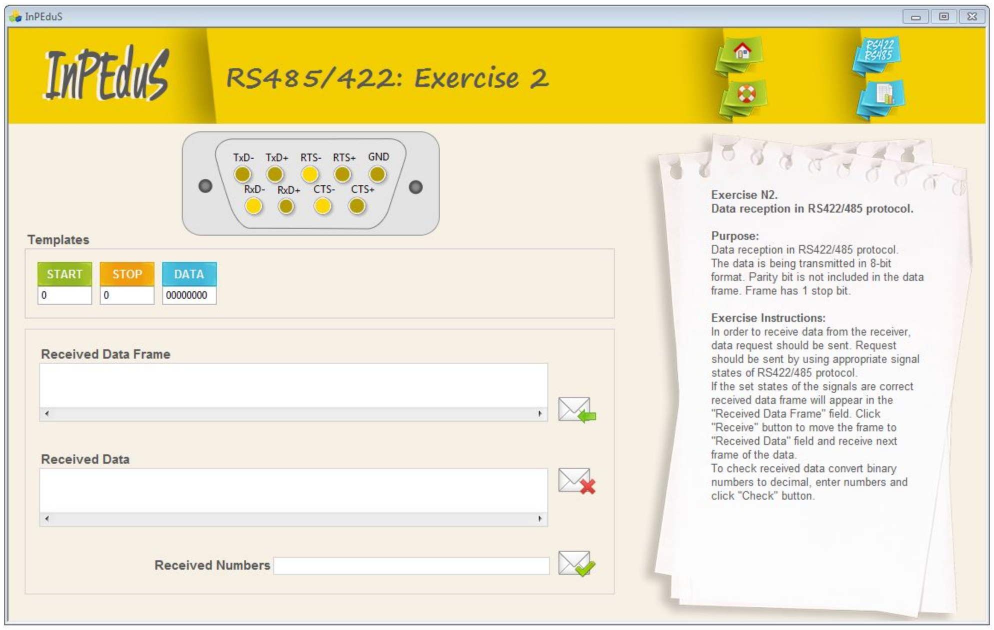
If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

Exercise №2. Data reception in RS422/485 protocol.

The purpose of the exercise is a study of data reception in RS422/485 protocol.



START	STOP	DATA
0	0	00000000

Exercise N2.
Data reception in RS422/485 protocol.

Purpose:
Data reception in RS422/485 protocol.
The data is being transmitted in 8-bit format. Parity bit is not included in the data frame. Frame has 1 stop bit.

Exercise Instructions:
In order to receive data from the receiver, data request should be sent. Request should be sent by using appropriate signal states of RS422/485 protocol.
If the set states of the signals are correct received data frame will appear in the "Received Data Frame" field. Click "Receive" button to move the frame to "Received Data" field and receive next frame of the data.
To check received data convert binary numbers to decimal, enter numbers and click "Check" button.

The data is being transmitted in 8-bit format. Parity bit is not included in the data frame. Frame has 1 stop bit.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

In order to receive data from the receiver, data request should be sent. Request should be sent by using appropriate signal states of RS422/485 protocol.

If the set states of the signals are correct received data frame will appear in the **"Received Data Frame"** field. Click **"Receive"** button to move the frame to **"Received Data"** field and receive next frame of the data.

In case of error within the signals' states Warning Indicator will turn red. Correct signal's states and click the **"Receive"** button once more.

To check received data convert binary numbers to decimal, enter numbers and click **"Check"** button. If the numbers within the frame are correct, the dialog box will appear with "Correct!" text, the dialog with "Incorrect!" text will appear in opposite case.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **"Report"** button to create the report.

If the exercise is not finished after **"Report"** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

6. Protocol Modbus

Modbus is communication protocol based on client-server architecture. It is widely used in IT to organize connection between electrical devices. The protocol can be used to transfer data through serial connection lines RS-485, RS-422, RS-232, as well as TCP/IP network (Modbus TCP). Modbus was designed by Modicon Company. It was published in 1979 for the first time.

Modbus protocol has 2 modifications Modbus Plus and Modbus TCP. Modbus Plus is multi-master protocol with cyclic marker transmission, and Modbus TCP is intended to be used in Ethernet and Internet networks. Modbus protocol itself has two transmission modes: RTU (Remote Terminal Unit) and ASCII. Standard considers that RTU mode should exist in Modbus protocol obligatorily and the ASCII mode is optional.

The basic characteristic of the protocol is that there is only one master in the network. Modbus allows to design industrial network from one master and up to 247 slaves. Only master may initiate commands for remaining devices, which are slaves. The slave cannot start data transfer itself, or to request data from other devices. Master can also broadcast a request addressed to all devices in the network, in this case the response-message is not sent.

Transmission Modes

The transmission mode (Table 6-1) defines the structure of separate information blocks within the message, which is used for data transmission. There are 2 transmission modes in Modbus system. Both modes guarantee identical compatibility during connection with slaves. The mode is selected depending on device used as Master Modbus. For each Modbus system only a single mode should be used. Mode mixing is not allowed.

Table 6-1. ASCII and RTU mode characteristics

Characteristics	**ASCII (7-bit)**	**RTU (8-bit)**
Coding system	ASCII symbols 0-9. A-F are used	8-bit binary system
Number of bits per symbol		
Start bits	1	1
Data bits (LSB)	7	8
Parity	On/Off	On/Off
Stop bits	1 or 2	1 or 2
Checksum	LRC (Longitudinal Redundancy Check). LRC	CRC (Cyclical Redundancy Check). CRC_16

It is more comfortable to use ASCII symbols in debugging, so this mode is convenient for computers which are programmed with high level languages. The RTU mode is more convenient for computers which are programmed with machine level languages. In RTU mode data is transmitted as 8-bit binary symbol. In ASCII mode each RTU symbol is first divided into two 4-bit segments (most significant and least significant), is transformed into its hexadecimal equivalent and then is used for message generation. ASCII mode uses two times more symbols than RTU mode. But the decoding and data management is easier. The message symbols in RTU mode should be transmitted as continuous stream, whereas in ASCII mode it is allowed 1 sec delay between two adjacent symbols.

Modbus TCP

Modbus TCP as well as TCP/IP is used for data transmission within Ethernet network. TCP ADU for Modbus TCP has the following construction:

Transaction ID	Protocol ID	Packet Length	Slave's address	Function code	Data

- **Transaction ID**— 2 bytes, usually zeros.
- **Protocol ID** — 2 bytes, zeros.
- **Packet length** — two bytes, high and then low, the length of the subsequent packet segment.
- **Slave's Address** — Slave devices address, to which command is sent. Usually is ignored, if the connection is with specified device.

There is no checksum field in Modbus TCP.

Modbus RTU

Modbus RTU messages are transmitted as frames, for each of which the beginning and the end are known. The frame begins with delay of not less than 3.5 hexadecimal symbols (14 bits) duration. Frame should be transmitted continuously. If a delay of more than 1.5 hexadecimal symbols (6 bits) is found during transmission it is considered that the frame has an error and it should be declined by receiver. This delay values should be strictly complied for speeds lower than 19200 bit/sec, however for fast speeds it is recommended to use fixed delay values of 1.75ms and 750µs correspondingly.

In Modbus RTU protocol messages are transmitted as PDU (Protocol Data Unit) packets.

Function Code	Data

However to transmit the packet through physical layers PDU is placed in another packet, which has additional fields. This packet is called ADU (Application Data Unit). ADU format dependents on connection line type.

The general structure of ADU is as follows (dependent on realization, some fields can be missing):

Slave address	Function code	Data	Error detection block

Slave address is the address of the slave device, to which request is addressed. Slaves are responding only to those requests which have their address. The response starts with slave address, which can vary from 1 to 247. Address 0 is used for broadcast transmission it is received by every device. Addresses 248-255 are reserved.

Function code is a one-byte field. It informs the slave what actions or what data are required by master.

Data is the field with information, necessary for slave to take actions requested from master, or data transmitted from slave to master as a response. The length and format of the field depends on function number.

Error detection block (CRC) is the checksum for error checking in the frame. For sequential RS232/RS485 networks the maximal size of ADU is 256 bytes, and for TCP networks 260 bytes.

In Modbus RTU protocol data is transmitted by bytes in LSB format with addition of control bits (start, stop and parity bits).

In RTU mode default value for parity bit is 1, if the number of “1”-s within byte is odd, and 0, if the number is even. This parity is called even parity, and the control method is called parity control. Other type of parity control is odd parity, in this case, the parity bit is “1” if the number of logical “1”s within byte is even.

Start bit	1(LSB)	2	3	4	5	6	7	8	Parity bit	Stop bit

If Parity control is not used second stop bit is used instead of parity bit.

Error control in Modbus RTU

During data transfer errors of 2 types can take place.

- Errors connected with data corruption during transmission
- Logical errors

Errors of first type are detected with symbol frames, parity control and CRC-16-IBM (polynomial number 0xA001 is used).

In this case the least significant bit is transmitted first, opposite to address bytes and register value in PDU.

In RTU mode message should start and end with silence intervals, with duration of not less than the transmission time of 3.5 symbols with current speed in the network. Then device address is sent. After last transmitted symbol there is a delay of not less than 3.5 symbols duration as well. The new message can start after this interval.

Message frame is transmitted continuously. If the silence interval of more than 1.5 symbols length takes place, the frame should be ignored from receiver device.

Intervals (for Serial Modbus RTU): in case of speed 9600 bit/sec and 11 bits within frame (start bit + 8 data bits + parity control bit + stop bit): 3.5 * 11 / 9600 = 0.00401041(6), more than 4ms; 1.5 * 11 / 9600 = 0,00171875, more than 1ms. For speeds more than 19200 bit/sec intervals of 1,75 and 0,75 мс are allowed correspondingly.

CRC-16 (Cyclic Redundancy Check)

Message (only data bits, without taking into consideration start/stop bits and parity bit) is considered as a single binary number, in which MSB is transmitted first. The message is multiplied to X16 (is shifted to left by 16 bits), and then is divided to polynomial X16+X15+X2+1, expressed as binary number (11000000000000101). The integer part of the expression is ignored, and the 16-bit remainder (initialized with "1"s to avoid the case when the message consists of "0"s) is added to the message as 2 bytes checksum. Received message then is divided to the same polynomial in the receiver (X16+X15+X2+1). If there are no errors, remainder from the division is 0. The receiver can calculate the CRC and compare it to the received one. All arithmetic is done by module 2 (without transmission).

Device, which is used to prepare data for transmission, sends the LSB bit of each symbol first. During CRC calculation the first transmitted bit is defined as MSB of dividend. As the arithmetic is not using transmission, it is convenient to consider MSB to be in the right. This means that the bit order during calculations should be reversed. The polynomial MSB is ignored as it affects only on divider and not on remainder. As a result we get 1010 0000 0000 0001 (A001H). Note, that the reversing of the bit order has no effect on interpretation or bit order of data bytes during CRC calculation.

Step by step procedure of CRC-16 calculation is given below:

1. Load 16-digit register with number FFFFH.
2. Perform XOR operation on first data byte and the most significant byte of the register.
3. Put the result in register
4. Shift one bit to right in the register.
5. If the bit shifted right is "1", perform XOR operation on register and polynomial 1010 0000 0000 0001 (A001H).
6. If the shifted bit is "0", return to step 4.
7. Repeat steps 4 - 6 until 8 register shifts.
8. Perform XOR operation on next data byte and register.
9. Repeat steps 4-8 until XOR operation will be performed on all data bytes and register.
10. The value of register is 2 byte CRC and is added to the initial message in MSB format.

Modbus data-types and standard functions

Modbus specifies 4 data types:

- **Discrete Inputs** - one bit type, available only for read.
- **Coils** - one bit type, available for read and write
- **Input Registers** - 16-bit signed or unsigned type, available only for read.
- **Holding Registers** - 16-bit signed or unsigned type, available for read and write.

Data types of Modbus protocol are given in Table 6-2 :

Table 6-2. Modbus Data types

	Data type	**Access type**
Discrete Inputs	1 bit	Only read
Coils	1 bit	Read/write
Input Registers	16-bit word	Only read
Holding Registers	16-bit word	Read/write

To read values of these data functions with codes 1—4 (0x01—0x04) are used:

- 1 (0x01) —**Read Coil Status**.
- 2 (0x02) —**Read Discrete Inputs**.
- 3 (0x03) —**Read Holding Registers**.
- 4 (0x04) —**Read Input Registers**.

Request consists of the address of first element in the table (which value should be read) and the number of elements to read. Address and number of data are given with 16-bit numbers (MSB).

Requested data is transmitted within the response. Data byte quantity depends on the number of requested elements. 1 byte is transmitted before data transfer, with the value of data byte number.

Following functions are used to write one value:

- 5 (0x05) —**Force Single Coil**
- 6 (0x06) —**Preset Single Register**.

Command consists of element address (2 bytes) and set value (2 bytes). If the command is performed correctly, the slave returns request copy.

Following functions are used to write several values:

- 15 (0x0F) —Force Multiple Coils
- 16 (0x10) —Preset Multiple Registers.

Command consists of element address, the number of changing elements, number of transmitting data bytes and set values. In the response slave transmits initial address and the number of changed elements.

Logical errors

To inform about logical errors Modbus RTU provides opportunity for devices to send responses in case of error situations. Set most significant command bit can serve as a sign of error existence within message. An example is given in Table 6-3.

1. If the slave receives correct request and is able to perform it normally, it sends normal response.
2. If the slave denies the values, it does not send any response. Master diagnoses the error by time-out.
3. If the slave receives a request with detected error (parity, LRC, CRC), it does not send any response. Master diagnoses the error by time-out.
4. If the slave receives the request, but is not able to process (access to not existing register), a response with error data is sent.

Table 6-3. Response frame (Slave -> Master) in case of error in Modbus RTU

Transfer direction	Slave address	Function code	Data (or error code)	CRC
Request (Master→Slave)	0x01	0x77	0xDD	0xC7 0xA9
Response (Slave→Master)	0x01	0xF7	0xEE	0xE6 0x7C

If the slave receives request with correct address, but incorrect subsequent bytes (for instance, CRC and so on), it should send the response informing master about error.

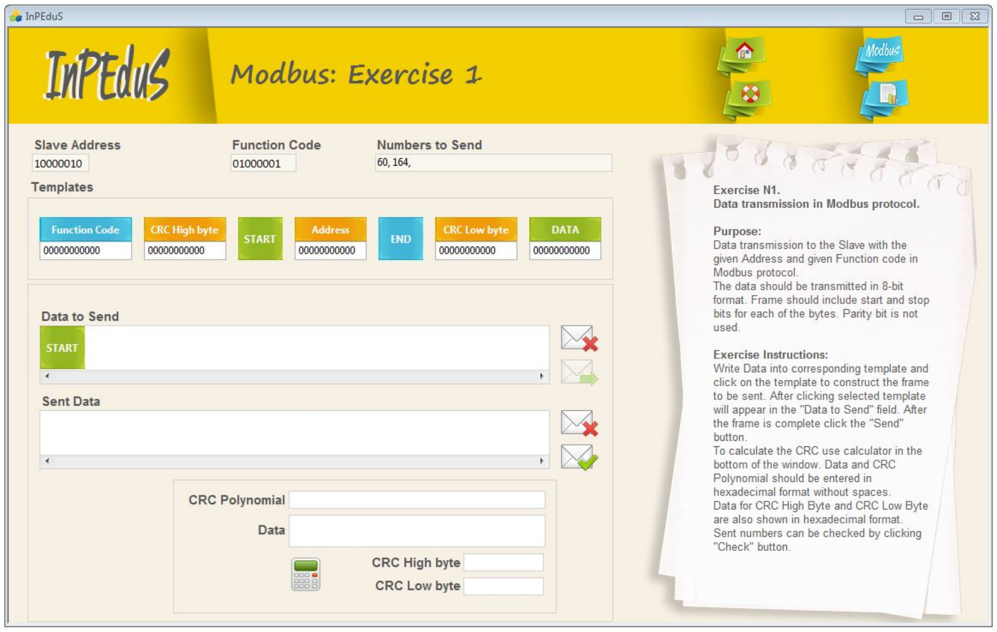
For this purpose, as a response 0x80 is added to the byte of function code, and the 3rd byte equals 0x02 – which is a standard signal showing error in received data in Modbus protocol.

Standard error codes

- 01 — the function code cannot be processed on slave.
- 02 — data address in the request is not available for current slave.
- 03 — value in data field is not allowed for current slave.
- 04 — unrecoverable error took place, when slave was trying to perform required actions.
- 05 — the slave has received the request and is processing it, but it takes a long time. This response prevents master from generating time-out error.
- 06 — the slave is processing a command. Master should repeat message afterwards, when the slave will be free.
- 07 — the slave is not able to perform program function, received in request. This code is used in case of unsuccessful program request, with function codes 13 and 14. Master should request diagnostic information or error information from slave.
- 08 — the slave tries to read extended memory, but detected parity error. Master should repeat the request, but usually in these cases a repair is needed.

Exercise №1. Data transmission in Modbus protocol.

The purpose of the exercise is a study of data transmission in Modbus protocol.



Slave Address: 10000010

Function Code: 01000001

Numbers to Send: 60, 164,

Function Code: 00000000000
CRC High byte: 00000000000
Address: 00000000000
CRC Low byte: 00000000000
DATA: 00000000000

Data to Send

Sent Data

CRC Polynomial

Data

CRC High byte

CRC Low byte

Exercise N1.
Data transmission in Modbus protocol.

Purpose:
Data transmission to the Slave with the given Address and given Function code in Modbus protocol.
The data should be transmitted in 8-bit format. Frame should include start and stop bits for each of the bytes. Parity bit is not used.

Exercise Instructions:
Write Data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the "Data to Send" field. After the frame is complete click the "Send" button.
To calculate the CRC use calculator in the bottom of the window. Data and CRC Polynomial should be entered in hexadecimal format without spaces.
Data for CRC High Byte and CRC Low Byte are also shown in hexadecimal format.
Sent numbers can be checked by clicking "Check" button.

The data is being transmitted in 8-bit format. Frame should include start and stop bits for each of the bytes. Parity bit is not used.

The program generates numbers to be sent automatically. These numbers are given in the **“Numbers to Send”** field on the top of the window. For data transmission Slave address and Function code should be mentioned.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the **“Data to Send”** field. After the frame is complete click the **“Send”** button.

In case of error within the frame Warning Indicator will turn red. Click the **“Clear”** button and assemble the frame once more. You can send all the numbers within one frame or each number within separate frames.

To calculate the CRC use calculator in the bottom of the window. Write down the polynomial in the **“CRC Polynomial”** field. Fill the **“Data”** field, and click **“Calculate CRC”** button afterwards. Data and CRC Polynomial should be entered in hexadecimal format without spaces.

Data for CRC High Byte and CRC Low Byte are also shown in hexadecimal format.

If the frame is constructed correctly, it will appear in the **“Sent Data”** field after clicking **“Send”** button. Sent numbers can be checked by clicking **“Check”** button. If the numbers within the frame are correct, the dialog box will appear with “Correct!” text, the dialog with “Incorrect!” text will appear in opposite case. Clear **“Data to Send”** and **“Sent Data”** fields in this case and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **“Report”** button to create the report.

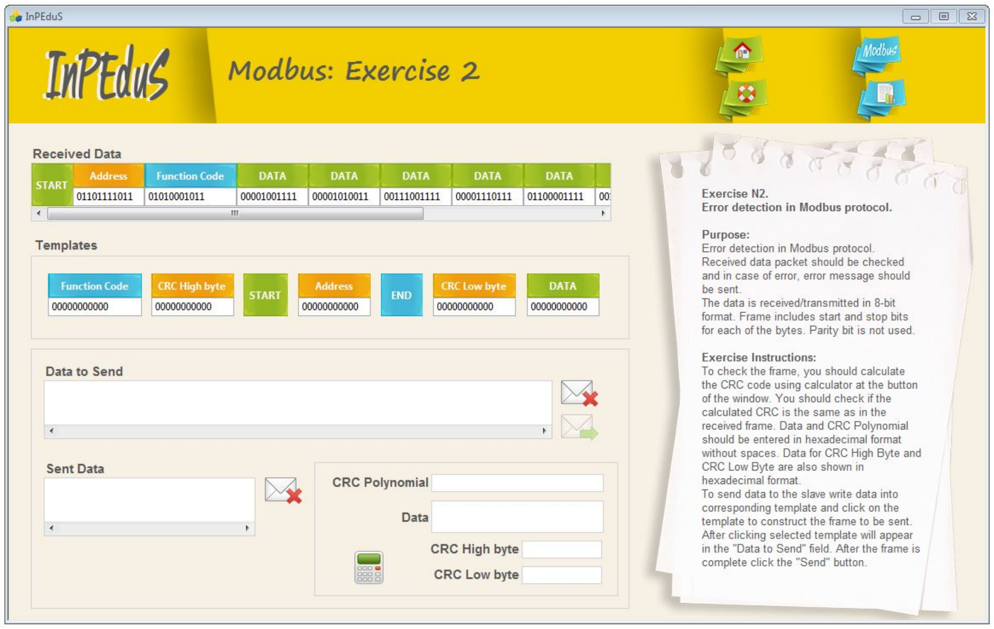
If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

Exercise №2. Error detection in Modbus protocol.

The purpose of this exercise is to check received data and send error message in Modbus protocol.



START	Address	Function Code	DATA	DATA	DATA	DATA	DATA
	01101111011	01010001011	00001001111	00001010011	00111001111	00001110111	01100001111

Function Code	CRC High byte	START	Address	END	CRC Low byte	DATA
00000000000	00000000000		00000000000		00000000000	00000000000

Exercise N2.
Error detection in Modbus protocol.

Purpose:
Error detection in Modbus protocol.
Received data packet should be checked and in case of error, error message should be sent.
The data is received/transmitted in 8-bit format. Frame includes start and stop bits for each of the bytes. Parity bit is not used.

Exercise Instructions:
To check the frame, you should calculate the CRC code using calculator at the button of the window. You should check if the calculated CRC is the same as in the received frame. Data and CRC Polynomial should be entered in hexadecimal format without spaces. Data for CRC High Byte and CRC Low Byte are also shown in hexadecimal format.
To send data to the slave write data into corresponding template and click on the template to construct the frame to be sent. After clicking selected template will appear in the "Data to Send" field. After the frame is complete click the "Send" button.

Received data packet should be checked and in case of error, error message should be sent.

Frame should include start and stop bits for each of the bytes. Parity bit is not used.

Data frame which should be checked is shown in the field **"Received Data"**.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

To check the frame, you should calculate the CRC code using calculator at the button of the window. You should check if the calculated CRC is the same as in the frame. In case of error response frame should be sent with error notification.

Click on the templates to construct the frame. After clicking, selected template will appear in the "**Data to Send**" field. In case of error within the frame Warning Indicator will turn red. Click the **"Clear"** button and assemble the frame once more.

After the frame is complete click the **"Send"** button, the frame will appear in the **"Sent Data"** field.

To calculate the CRC use calculator in the bottom of the window. Write down the polynomial in the **"CRC Polynomial"** field. Fill the **"Data"** field, and click **"Calculate CRC"** button afterwards. Data and CRC Polynomial should be entered in hexadecimal format without spaces.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **"Report"** button to create the report.

If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

7. Protocol GPIB

GPIB (General Purpose Interface Bus) is common purpose interface bus.

In the middle 1960s the company Hewlett Packard introduced Hewlett-Packard Interface Bus, HP-IB as a multipurpose controller. In the 1970s the standard was updated to more common GPIB, which is also known as standard IEEE-488. In the beginning of 1990s new specifications of the standard were released, as well as the new specification for programming language SCPI, which helped to simplify software development for measurement devices.

Software tools for GPIB bus are mostly being released by companies National Instruments and Keithley Instruments, the group of enthusiasts “Linux Lab Project” is also working on this topic.

Characteristics

Each device on the bus has unique 5-bit primary address (from 0 to 30). To avoid conflicts addresses should be different. Standard allows to connect to single 20 meter physical bus up to 15 devices.

It is possible to connect 3 different types of devices to the bus (Figure 7-1):

- Listener
- Talker
- Controller

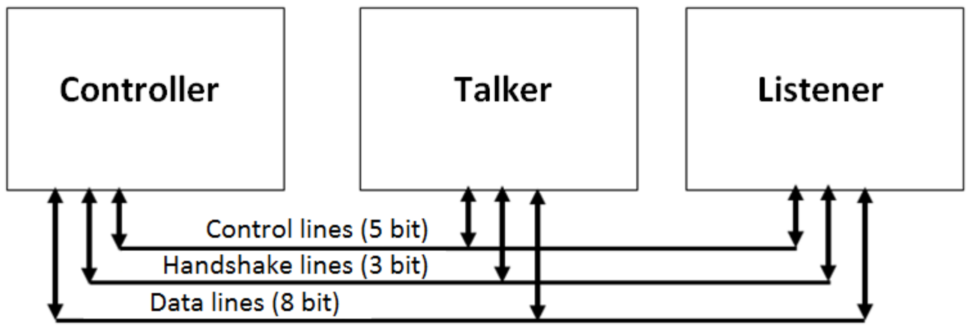


Figure 7-1 GPIB System

Listener is counting messages from the bus, and talker is sending messages to the bus. Only single device can serve as a talker, whereas the number of listeners can be arbitrary. The controller functions as an arbiter and defines which of the devices at the moment are talkers or listeners. Several controllers can be connected to the bus simultaneously. In this case one of the controllers (generally located on the GPIB interface card) is the responsible controller (Controller-in-Charge, CIC) and delegates its functions to other controllers as required.

Bus signal lines are related to one of the following 3 classes: data lines, handshake lines and interface control lines. 8 data lines are being used for command forwarding, the most significant bit (DIO8) is ignored in most cases. Data lines are numerated from 1 to 8, and not from 0 to 7, as it is done in the most of standards.

Handshake lines control data and command transfer and provide guaranteed reception of data by all listeners at proper time.

Signal examples are brought below:

Data Valid is used by talker to notify listeners that information prepared by talker is displayed on data lines and is ready to receive.

Not Ready for Data is used by listeners to inform talker that they are not ready to receive data. In this case talker stops information transfer until all the listeners are ready to continue dialog. The signal is realized in terms of “wired or” principle, which allows any listener to stop the transmission.

Not Data Accepted is used by listeners and informs talker that data is received by all addressers. If this signal is inactive, the talker is sure that all the clients have read the data from bus and it can transfer the next data byte. The handshaking procedure guarantees that data transfer speed within the bus does not exceed the data processing speed of the slowest client.

Talker displays new data on the bus only after all the listeners are ready for receive.

5 lines of interface control inform the devices connected to the bus what actions to take, in which mode to be and how to react on GPIB commands. The bus controller uses **Attention** line to inform clients that the bus is transmitting commands instead of data.

Service Request is available to any device on the bus. Controller shifts the device mode, which has sent this signal to talker and passes to it data transfer functions.

Interface Clear is used to initialize or reinitialize the bus.

Remote Enable shifts the mode of the device to execution of bus commands (and not control panel) mode and vice versa.

End of Identify is used by talker to identify the end of the message. Controller displays this signal to initiate parallel polls of devices connected to the bus.

IEEE-488 is 8-bit parallel bus containing 16 signal lines (8 bidirectional lines are used for data transfer, 3 for connection establishment, and 5 for bus control) and 8 wires for grounding.

All signal lines are using negative logic: the highest positive voltage is considered as logical “0”, and the lowest negative voltage as logical “1”. Data lines (DIO) are numerated from 1 to 8.

5 interface control lines inform the devices connected to the bus what actions to take, what mode to be in and how to react on GPIB commands.

Connectors

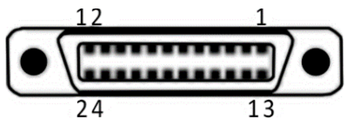


Figure 7-2 GPIB Connector

Connectors IEEE-488 (Figure 7-2)

Connector №	IEEE Name		Destination
1-4	Data input/output bit.	DIO1-DIO4	Data lines
5	End-or-identify.	EOI	Interface management line - The EOI line has two purposes – The Talker uses the EOI line to mark the end of a message string, and the Controller uses the EOI line to tell devices to identify their response in a parallel poll.
6	Data valid.	DAV	Handshake line - Tells when the signals on the data lines are stable (valid) and can be accepted safely by devices.
7	Not ready for data.	NRFD	Handshake line – Indicates when a device is ready or not ready to receive a message byte. The line is driven by all devices when receiving commands, by Listeners when receiving data messages, and by the Talker when enabling the HS488 protocol.
8	Not data accepted.	NDAC	Handshake line – Indicates when a device has or has not accepted a message byte. The line is driven by all devices when receiving commands, and by Listeners when receiving data messages.
9	Interface clear.	IFC	Interface management line - The System Controller drives the IFC line to initialize the bus and become CIC.
10	Service request.	SRQ	Interface management line - Any device can drive the SRQ line to asynchronously request service from the Controller.
11	Attention.	ATN	Interface management line - The Controller drives ATN true when it uses the data lines to send commands, and drives ATN false when a Talker can send data messages.
12	Shield	SHIELD	shield
13-16	Data input/output bit.	DIO5-DIO8	Data lines
17	Remote enable.	REN	Interface management line - The System Controller drives the REN line, which is used to place devices in remote or

			local program mode.
18	(wire twisted with DAV)	GND	Ground
19	(wire twisted with NRFD)	GND	Ground
20	(wire twisted with NDAC)	GND	Ground
21	(wire twisted with IFC)	GND	Ground
22	(wire twisted with SRQ)	GND	Ground
23	(wire twisted with ATN)	GND	Ground
24	Logic ground		“Logical Ground”

Commands

GPIB commands are being transferred through classical protocol IEEE-488.1. Standard gives format for the commands which are being sent by device and format and coding for responses. Commands usually are abbreviations of corresponding English expressions. A question mark is added to request-commands. All mandatory commands are prefixed with “*”. Standard defines minimal amount of opportunities which each device should be equipped with, including: receive and transmit data, send request for service and react on signal “Clear Interface”. All commands and the most data use 7-bit ASCII code, in which 8th bit is not used, or is used for parity.

Controller sends signals of 5 classes for getting information from devices connected to the bus and for bus reconfiguration:

- Uniline
- Universal Multiline
- Address Multiline
- Talk Address Group Multiline
- Listen Address Group Multiline

IEEE-488.2 Required and Optional Control Sequences

Description	Control Sequence	IEEE-488.2 Compliance
Send ATN-true commands	SEND COMMAND	Mandatory
Set address to send data	SEND SETUP	Mandatory
Send ATN-false data	SEND DATA BYTES	Mandatory
Send a program message	SEND	Mandatory
Set address to receive data	RECEIVE SETUP	Mandatory
Receive ATN-false data	RECEIVE RESPONSE MESSAGE	Mandatory

Receive a response message	RECEIVE	Mandatory
Pulse IFC line	SEND IFC	Mandatory
Place devices in DCAS	DEVICE CLEAR	Mandatory
Place devices in local state	ENABLE LOCAL CONTROLS	Mandatory
Place devices in remote state	ENABLE REMOTE	Mandatory
Place devices in remote with lockout state	SET RWLS	Mandatory
Place devices in local lockout state	SEND LLO	Mandatory
Read IEEE 488.1 status byte	READ STATUS BYTE	Mandatory
Send group execution trigger(GET) message	TRIGGER	Mandatory
Give control to another device	PASS CONTROL	Optional
Conduct a parallel poll	PERFORM PARALLEL POLL	Optional
Configure device's parallel poll Responses	PARALLEL POLL CONFIGURE	Optional
Disable device's parallel poll capability	PARALLEL POLL UNCONFIGURE	Optional

Second component of the command system is SCPI (Standard Commands for Programming Instruments), which was accepted in 1990. SCPI defines standard rules for keyword abbreviation, which should be used as commands. Keywords can be used either in long (for example, MEASure) or in short (MEAS - measure) writing forms. Commands in SCPI format are prefixed with colon. Command arguments are separated by comas. SCPI standard operates with programming instrument model. Functional components of this model include measurement system (subsystems "Input", "Sensor" and "Calculator"), signal generation system (subsystems "Calculator", "Source" and "Output") and subsystems "Format", "Display", "Memory" and "Trigger".

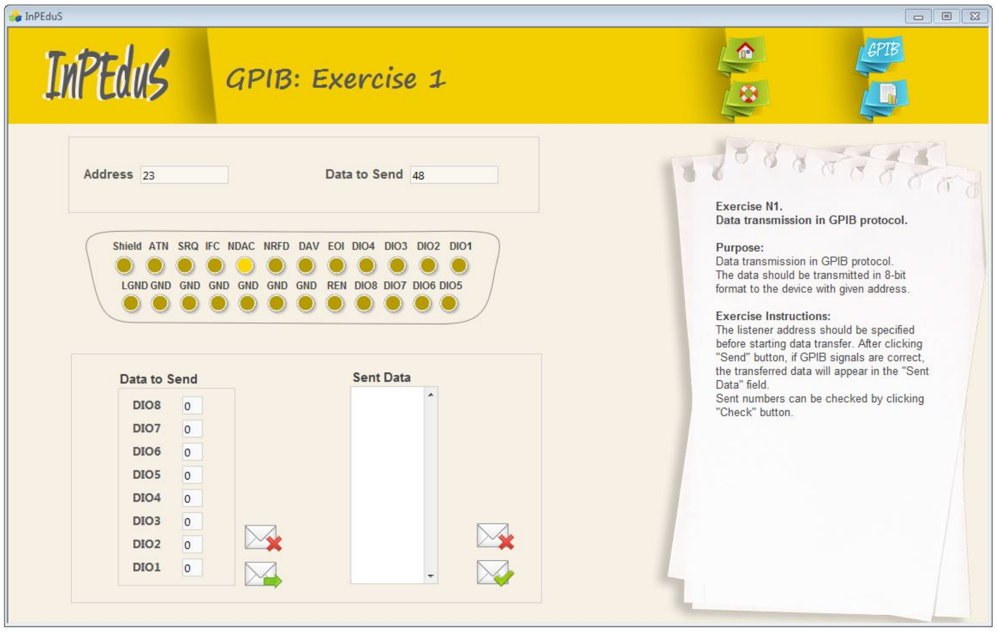
488.2 Controller protocols

Protocols are high-level routines that combine a number of control sequences to perform common test system operations. IEEE 488.2 defines two required protocols and six optional protocols, as shown in Table 2. These protocols reduce development time because they combine several commands to execute the most common operations required by any test system. The RESET protocol ensures that the GPIB has been initialized and all devices have been cleared and set to a known state. The ALLSPOLL protocol serial polls each device and returns the status byte of each device. The PASSCTL and REQUESTCTL protocols pass control of the bus between a numbers of different devices. The TESTSYS protocol instructs each device to run its own self-tests and report back to the Controller whether it has a problem or is ready for operation. Perhaps the two most important protocols are FINDLSTN and FINDRQS. The FINDLSTN protocol takes advantage of the IEEE 488.2 Controller capability of monitoring bus lines to locate listening devices on the bus. The Controller implements the FINDLSTN protocol by issuing a particular listen address and then monitoring the NDAC handshake line to determine if a device exists at that address. The result of the FINDLSTN protocol is a list of addresses for all the located devices. FINDLSTN is used at the start of an application program to ensure proper system configuration and to provide a valid list of GPIB devices that can be used as the input parameter to all other IEEE 488.2 protocols. The bus line monitoring capability of an IEEE 488.2 Controller is also useful to detect and diagnose problems within a test system. The FINDRQS protocol is an efficient mechanism for locating and polling devices that are requesting service. It uses the IEEE 488.2 Controller capability of sensing the FALSE to TRUE transition of the SRQ line. You prioritize the input list of devices so that the more critical devices receive service first. If the application program can jump to this protocol immediately upon the assertion of the SRQ line, you increase program efficiency and throughput.

Keyword	Name	Compliance
RESET	Reset System	Mandatory
ALLSPOLL	Find Device Requesting Service	Optional
FINDRQS	Serial Poll All Devices	Mandatory
PASSCTL	Pass Control	Optional
REQUESTCTL	Request Control	Optional
FIDLSTN	Find Listeners	Optional
TESTSYS	Self-Test System	Optional
SETADD	Set Address	Optional, but requires FINDLSTN

Exercise №1. Data transmission in GPIB protocol.

The purpose of the exercise is the study of data transmission in GPIB protocol.


InPEduS
GPIB: Exercise 1
GPIB
Shield ATN SRQ IFC NDAC NRFD DAV EOI DIO4 DIO3 DIO2 DIO1
LGND GND GND GND GND GND GND REN DIO8 DIO7 DIO6 DIO5

Address 23

Data to Send 48

Data to Send

DIO8	0
DIO7	0
DIO6	0
DIO5	0
DIO4	0
DIO3	0
DIO2	0
DIO1	0

Sent Data

Exercise N1.
Data transmission in GPIB protocol.

Purpose:
Data transmission in GPIB protocol.
The data should be transmitted in 8-bit format to the device with given address.

Exercise Instructions:
The listener address should be specified before starting data transfer. After clicking "Send" button, if GPIB signals are correct, the transferred data will appear in the "Sent Data" field.
Sent numbers can be checked by clicking "Check" button.

The data is being transmitted in 8-bit format with given address.

In the top of the window is given the **“Listener Address”** of the receiver device. The program automatically generates numbers to be sent, which are being displayed on **“Numbers to Send”** field in the top of the window.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

The listener address should be specified before starting data transfer. Convert address from decimal format to binary and write down the binary code in **“Data to Send”** fields. Enable ATN and DAV signals and click the **“Send”** button.

In case of error within the frame Warning Indicator will turn red. Click the **“Clear”** button and fill the fields correctly.

To send the data disable the signal ATN, convert the data from decimal to binary format and write down the binary code into **“Data to Send”** fields. You can send several numbers within single transfer.

The transferred data will appear in the **“Sent Data”** field after clicking **“Send”** button. Sent numbers can be checked by clicking **“Check”** button. If the numbers are correct, the dialog box will appear with “Correct!” text, the dialog with “Incorrect!” text will appear in opposite case. Clear **“Data to Send”** and **“Sent Data”** fields in this case and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **“Report”** button to create the report.

If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

8. Protocol TCP

TCP (Transmission Control Protocol) is one of the main Internet protocols, intended for data transmission management in TCP/IP networks and sub-networks. TCP is functioning as transport layer protocol of OSI model.

TCP — is transport mechanism, which provides data stream, with preset connection. Protocol guarantees the reliability of received data, performs second request for data, if data is lost and eliminates duplicated data, if 2 copies of the same packet are received. Unlike UDP, TCP guarantees that no data will be lost during transmission, and notifies the sender for transmission results. TCP segment format is shown on Figure 8-1.

0 15			16 31
Source Port			Destination Port
Sequence number			
Acknowledgement number (if ACK set)			
Data offset	Reserved	Flags	Window size
Checksum			Urgent pointer (if URG set)
Options			Padding
Data			
....			

Figure 8-1 TCP segment format

Source port identifies client application, from which packets are sent.

Destination port identifies port, data is sent to.

Specified ports are attached to number of services that use TCP for transmission: 20/21 — FTP, 22 — SSH, 23 — Telnet, 25 — SMTP, 80 — HTTP, 110 — POP3, 194 — IRC (Internet Relay Chat), 443 — HTTPS (Secure HTTP), 1863 — MSN Messenger, 2000 — Cisco SCCP (VoIP), 3389 — RDP, 8080 —HTTP Alternate port.

Sequence number has 2 options:

1. If SYN (synchronize) flag is set, this is ISN (Initial Sequence Number). First byte, which will be transmitted in next packet will have sequence number equal to ISN + 1.

2. If SYN is not set, first data byte, which is transmitted in current packet has this sequence number.

Acknowledgement number – this is next sequence number, which receiver is expecting. This is SN (sequence number) + 1 of the last successfully received data byte. This field is used only if the ACK flag is set to 1.

Offset This field specifies TCP header size in 4-byte words. Minimal size is 5 words and the maximal 15, which is 20 and 60 bytes correspondingly.

Reserved for future use (6 bits), should be set to 0. 5th and 6th bits of this field are already defined.

- **CWR** (Congestion Window Reduced) flag is set by sender to indicate that a packet with ECE (RFC 3168) flag set is received.
- **ECE** (ECN-Echo) — identifies that specified node have ECN (explicit congestion notification) option and to notify the sender about congestions in the network (RFC 3168).

Flags (Control bits). This field contains 6 1-bit flags.

- **URG** Urgent pointer field is significant.
- **ACK** Acknowledgement field is significant
- **PSH** Push function. Asks to push the buffered data to receiver application.
- **RST** Reset the connection.
- **SYN** Synchronize sequence numbers.
- **FIN** Final. FIN bit is used for connection termination.

Window Size. The value of this field defines number of data bites that the sender wants to receive.

Pseudo header. TCP-header does not provide information of source and destination addresses. This means that even if the destination port is correct, it cannot guarantee that the message has found its destination. As the purpose of TCP is reliable delivery of messages, this point has essential importance. This problem could be solved in variety of ways. The simplest was to add address information to TCP header, however, this would first bring to duplicated information, and second, breaks the encapsulation principle of OSI model. This was the reason that developers decided to use additional pseudo-header (Table 8-1 and Table 8-2):

Table 8-1. IPv4 TCP pseudo header

Bits	0-7								8-15	16-31
0-31	Source address									
32-63	Destination address									
64-95	0	0	0	0	0	0	0	0	Protocol	TCP length

Table 8-2 IPv6 pseudo header

Bits	0-23																							24-31
0-96	Source address																							
128-224	Destination address																							
256	TCP length																							
288	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Next header

- Protocol/ Next header — has the value 6 (000000110 in binary format, 0x6 — in hexadecimal) —TCP-protocol identifier.
- TCP length —TCP length in bytes (TCP-header + data, pseudo header length is not considered).

Pseudo header is not a part of TCP segment. It is used to calculate checksum before the message is sent and after it is received.

Checksum. Checksum field is 16-bit complement of sum of all 16-bit words in header (including pseudo header) and the data. Before checksum calculation 0 bits are added until the datagram length is multiple of 16 bits (pseudo header and added 0s are not sent with the datagram). During checksum calculation the Checksum field within UDP header is considered as 0. For checksum calculation pseudo header and UDP-message are divided into words (1 word = 2 bytes = 16 bits).

When the message is received the receiver re-computes checksum, taking into consideration the checksum field. If binary value of 16 "1"s is obtained in the result, the checksum is considered descended. If the sum does not descend the datagram is being deleted.

An example of checksum computation is given below.

Message: 0x4500003044224000800600008c7c19acae241e2b.

First the sum of 16 bit words should be calculated:

4500 + 0030 + 4422 + 4000 + 8006 + 0000 + 8c7c + 19ac + ae24 + 1e2b = 2BBCF

BBD1 = 2 + BBCF = 1011101111010001

Checksum = complement (1011101111010001) = 0100010000101110 = 442E

Urgent pointer. 16-bit value of positive offset from the sequence number in current segment. This field indicates the octet sequence number with which significant data ends. The field is used only if the URG flag is set.

Options. Can be used in several situations to expand the protocol. Sometimes are used for testing.

Protocol operation

Unlike UDP, which can start data transmission immediately, TCP sets connections, which should be created before data transfer. TCP connections can be divided into 3 states: connection establishment, data transmission and connection termination.

- **Connection establishment** TCP séance start, defined as handshaking, consists of 3 steps:

    1. Client that tries to establish connection, sends a segment with sequence number and SYN flag to server. Server receives segment, saves sequence number and tries to create socket for new client service. In case of success server sends a segment with sequence number and ACK and SYN flags to client, and goes to SYN-RECEIVED state. In case of failure server sends to client a segment with RST flag.
    2. If client receives a segment with SYN flag, it saves the sequence number and sends a segment with ACK flag. If it receives also the ACK flag, client goes to ESTABLISED state. If the client receives RST flag, it stops trying to connect. If the client does not receive response within 10 seconds, it repeats connection process once more.
    3. If server receives a segment with ACK flag in SYN-RECEIVED state, it goes to ESTABLISHED state. In opposite case it closes the socket after time out and goes to CLOSED state.

    This process is called three way handshake, as despite possibility to establish connection within 4 segments (SYN to server, ACK to client, SYN to client, ACK to server), practically 3 segments are used to save time.

- **Data transmission.** During data transfer receiver uses the sequence number from received segments to recover their initial order. Receiver notifies the transmitter the sequence number to which it successfully received data, including this number to Acknowledgment number field. All received data in confirmed sequence range are ignored. If the received segment contains larger sequence number, then expected, data from the segment are buffered, but the sequence number is not changed. If in future a segment with expected sequence number is received, data order will be automatically recovered taking into account sequence numbers in segments.

    To make sure that transmitter does not send data faster than the receiver can process it, TCP has options to control stream. The field “Window size” is used for this purpose. In segments, sent from receiver, current size of receiver buffer is indicated. Transmitter saves the window size and sends data no more than indicated by receiver. If the receiver has sent the window size of 0, data transmission in this direction stops, until receiver informs of larger window size.

    There are cases, when the transmitter application can require to “push” some data sequence to receiver without buffering. PSH flag is used for these purposes. If the PSH is set in received segment, TCP realization sends all currently buffered data to receiver application. “Push” is used, as an instant, in interactive applications.

- **Connection termination** has 3 steps:

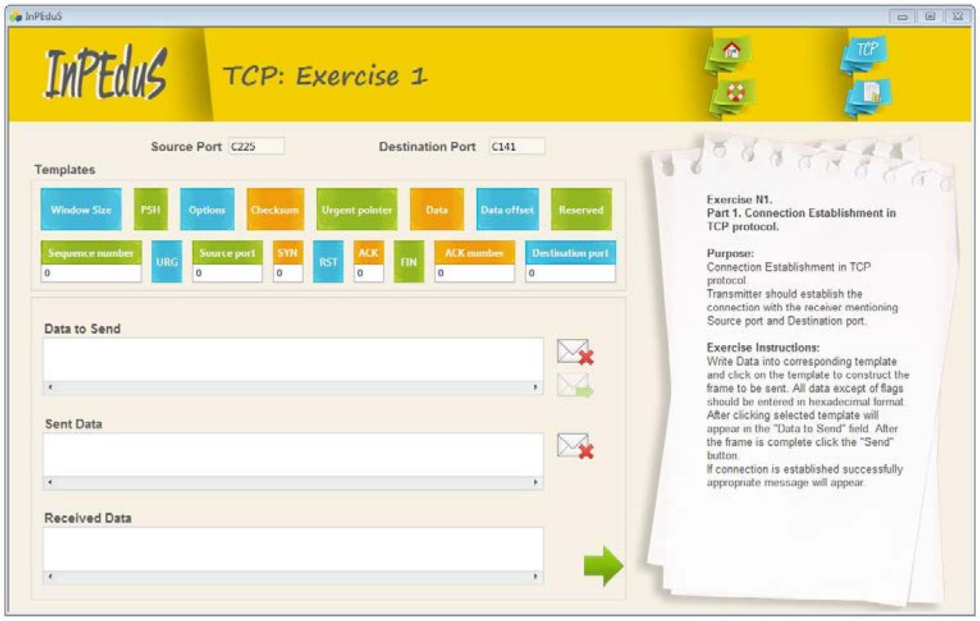
    1. FIN and ACK flags are sent to server on connection termination.

2. ACK, FIN, response flags are sent from server to client, informing that connection is closed.
3. After reception of these flags client closes connection and sends to server ACK to confirm that connection is closed.

Exercise №1. Data transmission in TCP protocol.

1. Connection Establishment in TCP protocol

The purpose of the exercise is a study of connection establishment in TCP protocol. Transmitter should establish the connection with the receiver mentioning Source port and Destination port.



Exercise N1.
Part 1. Connection Establishment in TCP protocol.

Purpose:
Connection Establishment in TCP protocol.
Transmitter should establish the connection with the receiver mentioning Source port and Destination port.

Exercise Instructions:
Write Data into corresponding template and click on the template to construct the frame to be sent. All data except of flags should be entered in hexadecimal format. After clicking selected template will appear in the "Data to Send" field. After the frame is complete click the "Send" button.
If connection is established successfully appropriate message will appear.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding template and click on the template to construct the frame to be sent. All data except of flags should be entered in hexadecimal format. After clicking selected template will appear in the **“Data to Send”** field. After the frame is complete click the **“Send”** button.

In case of error within the frame Warning Indicator will turn red. Click the **“Clear”** button and assemble the frame once more.

If the frame is constructed correctly and connection is established appropriate message will appear. Sent data will appear in the **“Sent Data”** field, and response frame will appear in the **“Received Data”** field. In case of errors clear **“Data to Send”** and **“Sent Data”** fields and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **“Report”** button to create the report.

If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

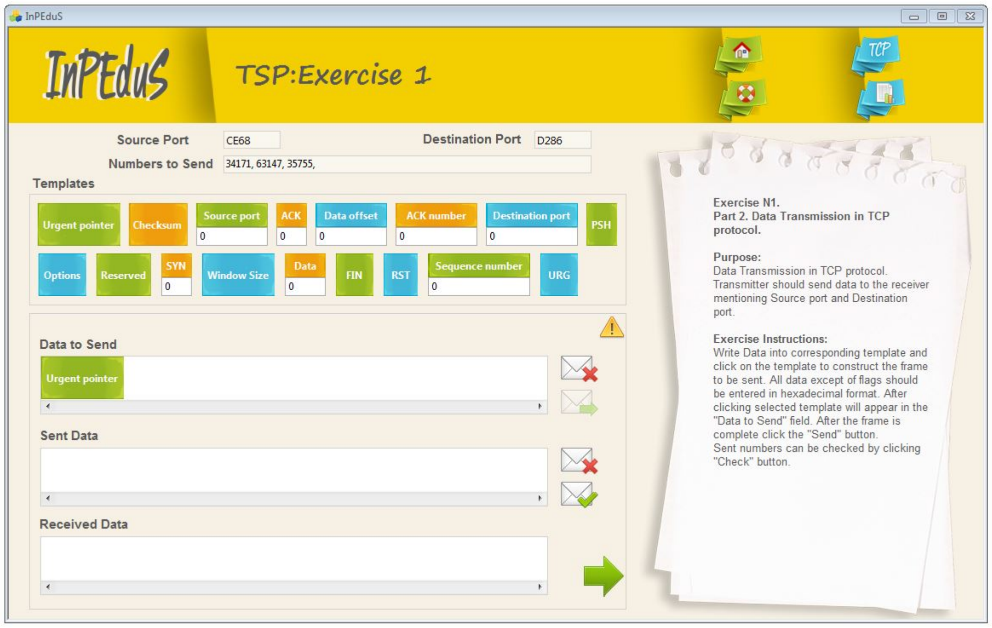
If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

Click **“Part 2”** button to go to the second part of the exercise.

2. Data Transmission in TCP protocol

The purpose of the exercise is a study of data transmission in TCP protocol. Transmitter should send data to the receiver mentioning Source port and Destination port.



Source Port: CE68
Destination Port: D286
Numbers to Send: 34171, 63147, 35755,

Exercise N1.
Part 2. Data Transmission in TCP protocol.

Purpose:
Data Transmission in TCP protocol. Transmitter should send data to the receiver mentioning Source port and Destination port.

Exercise Instructions:
Write Data into corresponding template and click on the template to construct the frame to be sent. All data except of flags should be entered in hexadecimal format. After clicking selected template will appear in the "Data to Send" field. After the frame is complete click the "Send" button.
Sent numbers can be checked by clicking "Check" button.

The program generates numbers to be sent automatically. These decimal numbers are given in the **“Numbers to Send”** field on the top of the window.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding template and click on the template to construct the frame to be sent. All data except of flags should be entered in hexadecimal format. After clicking selected template will appear in the **“Data to Send”** field. After the frame is complete click the **“Send”** button.

In case of error within the frame Warning Indicator will turn red. Click the **“Clear”** button and assemble the frame once more.

If the frame is constructed correctly, it will appear in the **"Sent Data"** field after clicking **"Send"** button, and response frame will appear in the **"Received Data"** field.

Sent numbers can be checked by clicking **"Check"** button. If the numbers within the frame are correct, the dialog box will appear with "Correct!" text, the dialog with "Incorrect!" text will appear in opposite case. Clear **"Data to Send"** and **"Sent Data"** fields in this case and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **"Report"** button to create the report.

If the exercise is not finished after **"Report"** button is pressed corresponding dialog will appear and the report will not be generated.

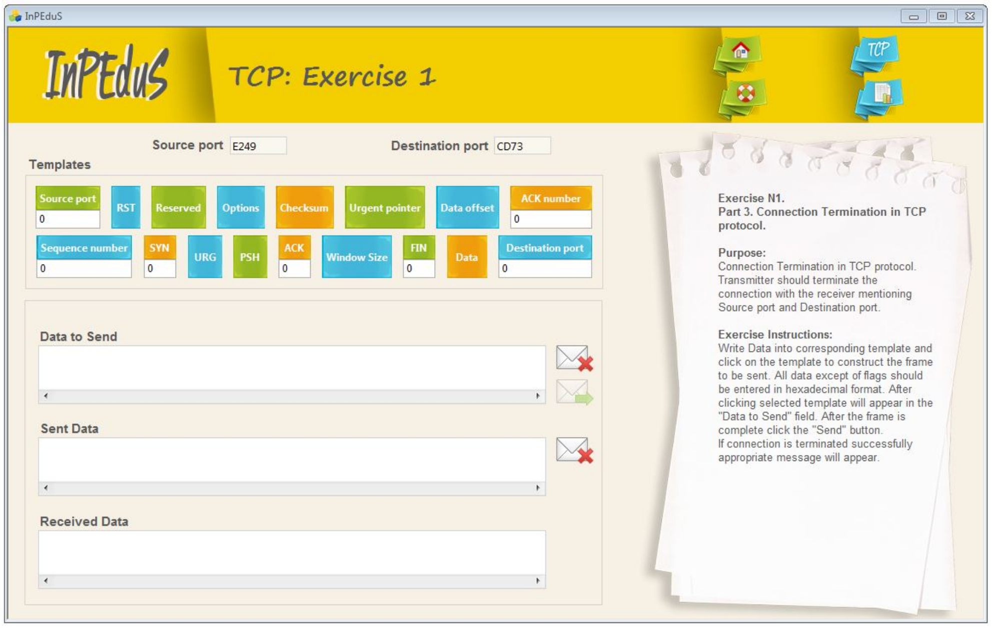
If the exercise is finished correctly, window will appear after pressing **"Report"** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

Click **"Part 3"** button to go to the third part of the exercise.

3. Connection Termination in TCP protocol

The purpose of the exercise is a study of connection termination in TCP protocol. Transmitter should terminate the connection with the receiver mentioning Source port and Destination port.



Exercise N1.
Part 3. Connection Termination in TCP protocol.

Purpose:
Connection Termination in TCP protocol. Transmitter should terminate the connection with the receiver mentioning Source port and Destination port.

Exercise Instructions:
Write Data into corresponding template and click on the template to construct the frame to be sent. All data except of flags should be entered in hexadecimal format. After clicking selected template will appear in the "Data to Send" field. After the frame is complete click the "Send" button.
If connection is terminated successfully appropriate message will appear.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding template and click on the template to construct the frame to be sent. All data except of flags should be entered in hexadecimal format. After clicking selected template will appear in the **“Data to Send”** field. After the frame is complete click the **“Send”** button.

In case of error within the frame Warning Indicator will turn red. Click the **“Clear”** button and assemble the frame once more.

If the frame is constructed correctly, it will appear in the **“Sent Data”** field after clicking **“Send”** button, and response frame will appear in the **“Received Data”** field.

If the frame is constructed correctly and connection is established appropriate message will appear. In case of errors clear **“Data to Send”** and **“Sent Data”** fields and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **“Report”** button to create the report.

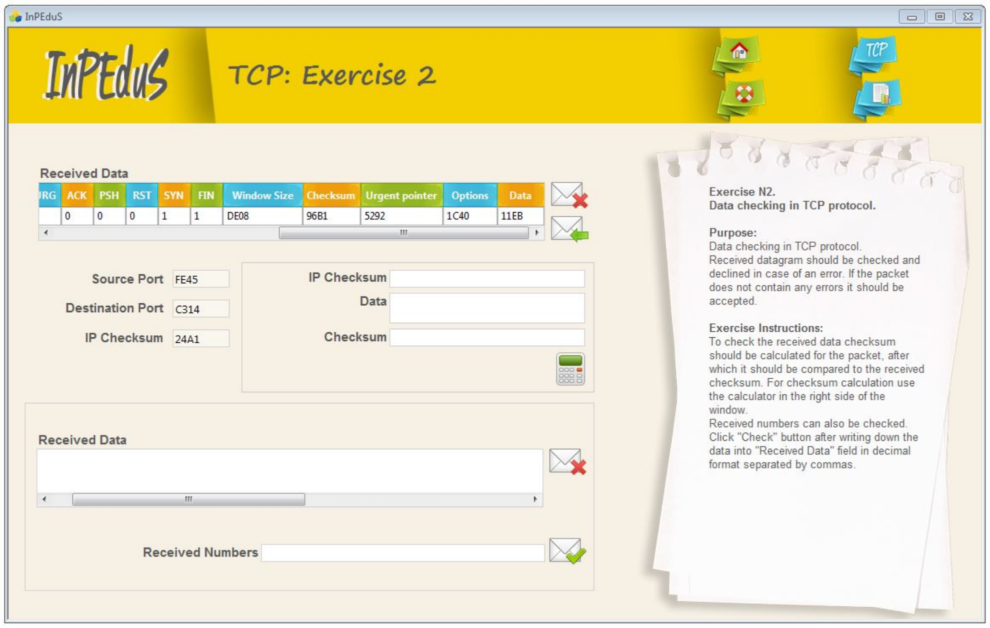
If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

Exercise №2. Data checking in TCP protocol.

The purpose of the exercise is data checking and error detection in TCP protocol.



Received Data

RG	ACK	PSH	RST	SYN	FIN	Window Size	Checksum	Urgent pointer	Options	Data
	0	0	0	1	1	DE08	96B1	5292	1C40	11EB

Source Port FE45
Destination Port C314
IP Checksum 24A1

IP Checksum
Data
Checksum

Received Data

Received Numbers

Exercise N2.
Data checking in TCP protocol.

Purpose:
Data checking in TCP protocol.
Received datagram should be checked and declined in case of an error. If the packet does not contain any errors it should be accepted.

Exercise Instructions:
To check the received data checksum should be calculated for the packet, after which it should be compared to the received checksum. For checksum calculation use the calculator in the right side of the window.
Received numbers can also be checked. Click "Check" button after writing down the data into "Received Data" field in decimal format separated by commas.

Received data is given in the top of the window. Received datagram should be checked and declined in case of an error. If the packet does not contain any errors it should be accepted.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

To check the received data checksum should be calculated for the packet, after which it should be compared to the received checksum. For checksum calculation use the calculator in the right side of the window. Data should be written in the hexadecimal format in **"IP Checksum"** and **"Data"** fields. Click the **"Calculate Checksum"** button. The calculated code in hexadecimal format will be displayed in the **"Checksum field"**.

If the received datagram is correct, frame will appear in the **"Received Data"** field after pressing **"Receive"** button. In case of error within the frame click **"Decline"** button, and next datagram will appear. If the **"Receive"** button is pressed when there is an error, the warning indicator will turn to red.

Received numbers can also be checked. Click **"Check"** button after writing down the data into **"Received Data"** field in decimal format separated by commas. If the numbers are correct, the dialog box will appear with "Correct!" text, the dialog with "Incorrect!" text will appear in opposite case. Clear fields in this case and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **"Report"** button to create the report.

If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

9. Protocol UDP

UDP (User Datagram Protocol) protocol was created by David P. Ride in 1980 and was officially defined in RFC 768. Protocol is designed to transferring of datagrams between computer processes, which are connected through single network with frame commutation and it is one of the key elements of **Internet Protocol Suite** (also known as **TCP/IP**). With UDP computer applications can send datagrams (messages) to other hosts through IP-network without need of initial message to install special transfer channels.

UDP uses a simple model for transmission and provides unsafe service. As a result datagrams can linger, be lost, duplicated or be received not in order. UDP implies that error checking and correction either is not necessary or should be implemented in applications. Time-sensitive applications frequently use UDP, as it is more preferable to lose frames than to wait for lingering frames, which can be impossible in real time systems.

UDP is a stateless protocol which is also useful for servers, which are responsible for small requests from big amount of clients, for instance streaming multimedia applications (IPTV, VoIP and most online games).

Service Ports

UDP-applications use datagram sockets to apply connections between hosts. Application binds the socket to its end point of data transmission, which is combination of IP address and service port. Port is software structure defined by port ID with 16-bit integer value (from 0 to 65535). 0 port is reserved, although it is a valid value for source port in the case if the sender does not wait for response messages.

IANA (Internet Assigned Numbers Authority) has separated 3 groups of port IDs.

- Ports with numbers from 0 to 1023 are used for usual, well-known services.
- Port numbers from 1024 to 49151 are used for registered IANA services.
- Ports from 49152 to 65535 – are dynamic ports and can be used for any purposes, as officially they are not designed for any specified service.

A number of ports is registered for standard purposes. Example is given in Table 9-1.

Table 9-1.

Port ID	**Designation**	**Purpose**
1397	Audio-activmail	Active voice mail
1398	Video-activmail	Active video-mail
5002	RFE	Radio-Ethernet
6000-6063	X11	X Window System
7008	AFS3-update	Server-server actualization

Packet structure

UDP does not give any guarantee for message delivery for high level protocol and does not save states of sent messages. This is the reason that UDP is also called Unreliable Datagram Protocol.

UDP provides multichannel transfer and header integrity and essential data checking. The UDP datagram format is given in Figure 9-1.

0 15	16 31
UDP Source port	UDP Destination port
UDP message length	Checksum
Data	
…….	

Figure 9-1 UDP datagram format

UDP header consists of 4 fields, each of 2 byte length (16 bits). Two of these fields are optional if using IPv4, whereas in IPv6 only source port is optional.

- **Source Port, 16 bits.** This field, if needed (for instance the transmitter is waiting for a response), has the port ID from which the data packet was sent. If the field is not used it is filled with 0s.
- **Destination Port, 16 bits**. Computer port, to which data was sent.
- **Length, 16 bits.** Length (in bytes) of the current datagram, including header and data. The minimal length is 8 bytes (the length of the header). Maximal length of the packet is 65535 (8 bytes for the header and 65527 bytes for data). For IPv4 actual limit of the data length is 65507 (besides 8 bytes for the header 20 bytes are used for IP header). Maximal value of the field in case of IPv6 is 4,294,967,295 bytes (2^{32} - 1), 8 bytes from which are used for the header, and the remaining for the data.
- **Checksum, 16 bits.** Checksum of the UDP packet is bitwise complement of 16-bit words 16-bit sum (similar to TCP).

Checksum calculation

Before checksum calculation 0 bits are added until the datagram length is multiple of 16 bits (pseudo header and added 0s are not sent with the datagram). During checksum calculation the Checksum field within UDP header is considered as 0. For checksum calculation pseudo header and UDP-message are divided into words (1 word = 2 bytes = 16 bits).

After this all words are summed using one's complement arithmetic. The sum is then one's complemented and the value is written in the checksum field.

0 value of checksum is reserved, and it means that datagram does not have checksum. If the calculated checksum equals to 0, the field is filled with binary units.

When the message is received the receiver re-computes checksum, taking into consideration the checksum field. If binary value of 16 "1"s is obtained in the result, the checksum is considered descended. If the sum does not descend the datagram is being deleted.

An example of checksum computation is given below. The 16-bit words are: 0x398a, 0xf802, 0x14b2, 0xc281.

0x398a + 0xf802 = 0x1318c → 0x318d

0x318d + 0x14b2 = 0x0463f → 0x463f

0x463f + 0xc281 = 0x108c0 → 0x08c1

0x08c1 = 0000 1000 1100 0001 → 1111 0111 0011 1110 = 0xf73e — 0xffff − 0x08c1 = 0xf73e.

IPv4 Pseudo header

If UDP works on IPv4, checksum is calculated in terms of pseudo header, which gives some information from IPv4 header. Pseudo header is not a real IPv4 header, which is used for IP-packet transmission. Pseudo header for checksum calculation is given in Table 9-2.

Table 9-2

Bits	0 – 7	8 – 15	16 – 23	24 – 31
0	Source Address			
32	Destination Address			
64	0-s	Protocol	UDP length	
96	Source Port		Destination Port	
128	Length		Checksum	
160+	Data			

Source and destination addresses are taken from IPv4 header. For UDP the **Protocol** field value is 17. **UDP length field** gives the length of UDP header and data.

Checksum calculation is optional for IPv4. If it is not used the value is set to 0.

IPv6 Pseudo header

If working on IPv6 the checksum is a mandatory field in UDP datagram. During checksum calculation pseudo header, which imitates the real IPv6 header is also used (Table 9-3):

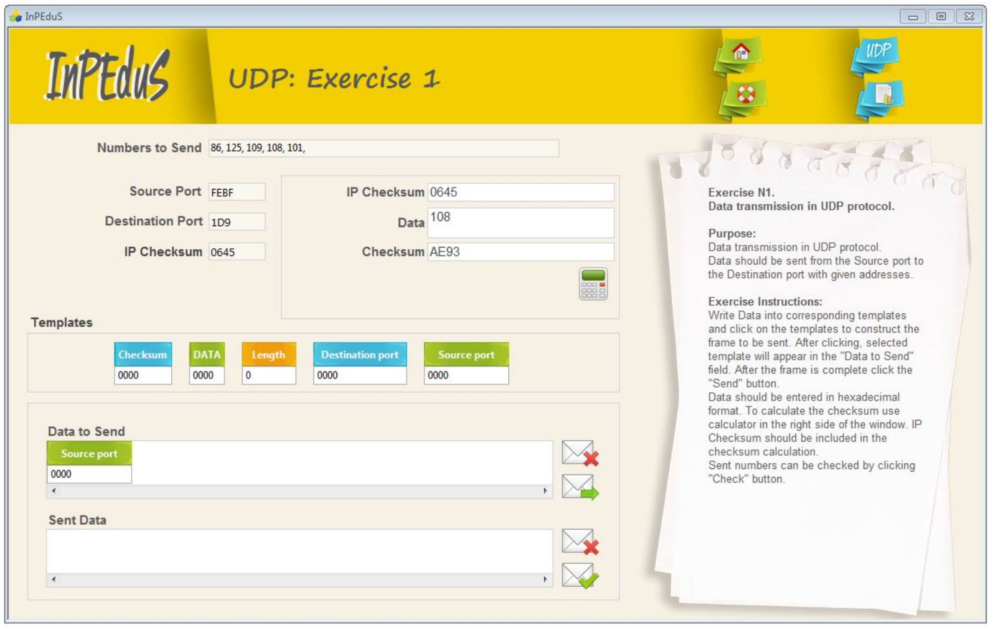
Table 9-3.

Bits	0 – 7	8 – 15	16 – 23	24 – 31
0	Source Address			
32				
64				
96				
128	Destination Address			
160				
192				
224				
256	UDP length			
288	0s			Next header
320	Source Port		Destination Port	
352	Length		Checksum	
384+	Data			

Source address is the same as in IPv6 header. Destination address is the final receiver, if there is no Routing header in IPv6-packet, this will be the destination address from IPv6 header, in opposite case, on the initial node this will be the value of the last element of the Routing header, and on the receiver node this will be the destination header from IPv6 header. The value of Next Header is the protocol value, which is 17 for UDP protocol. UDP length is the length of UDP header and the data.

Exercise №1. Data transmission in UDP protocol.

The purpose of the exercise is a study of data transmission in UDP protocol.



Numbers to Send: 86, 125, 109, 108, 101,

Source Port: FEBF
Destination Port: 1D9
IP Checksum: 0645

IP Checksum: 0645
Data: 108
Checksum: AE93

Checksum: 0000 | DATA: 0000 | Length: 0 | Destination port: 0000 | Source port: 0000

Data to Send: Source port 0000

Exercise N1.
Data transmission in UDP protocol.

Purpose:
Data transmission in UDP protocol.
Data should be sent from the Source port to the Destination port with given addresses.

Exercise Instructions:
Write Data into corresponding templates and click on the templates to construct the frame to be sent. After clicking, selected template will appear in the "Data to Send" field. After the frame is complete click the "Send" button.
Data should be entered in hexadecimal format. To calculate the checksum use calculator in the right side of the window. IP Checksum should be included in the checksum calculation.
Sent numbers can be checked by clicking "Check" button.

The data is being transmitted in hexadecimal format. All the templates should be filled with hexadecimal numbers.

The program generates numbers to be sent automatically. These numbers are given in the **"Numbers to Send"** field on the top of the window. 1 byte of information corresponds to each transmitting number.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

Write Data into corresponding templates and click on the templates to construct the frame to be sent. After clicking, selected template will appear in the **"Data to Send"** field. After the frame is complete click the **"Send"** button.

In case of error within the frame Warning Indicator will turn red. Click the **"Clear"** button and assemble the frame once more. You can send all the numbers within one frame or each number within separate frames.

To calculate the checksum use calculator in the right side of the window. Write down the the data in hexadecimal format in the fields **"IP Checksum"** and **"Data"** without spaces. Fill the **"Data"** field, and click **"Calculate Checksum"** button afterwards.

If the frame is constructed correctly, it will appear in the **"Sent Data"** field after clicking **"Send"** button.

Sent numbers can be checked by clicking **“Check”** button. If the numbers within the frame are correct, the dialog box will appear with “Correct!” text, the dialog with “Incorrect!” text will appear in opposite case. Clear **“Sent Data”** field in this case and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **“Report”** button to create the report.

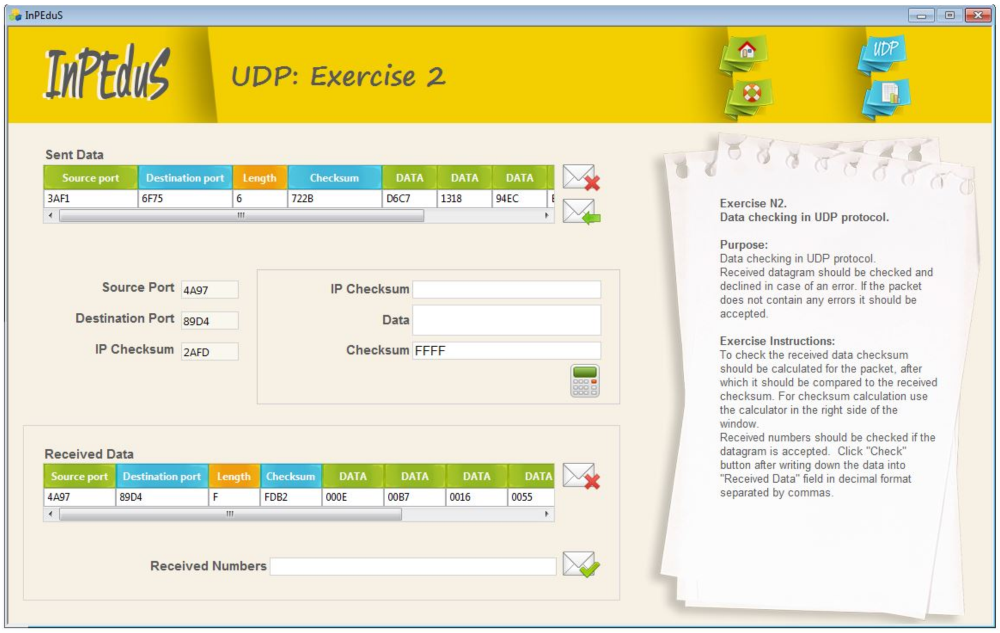
If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.

Exercise №2. Data checking in UDP protocol.

The purpose of the exercise is data checking and error detection in UDP protocol.



Sent Data

Source port	Destination port	Length	Checksum	DATA	DATA	DATA
3AF1	6F75	6	722B	D6C7	1318	94EC

Source Port 4A97
Destination Port 89D4
IP Checksum 2AFD

IP Checksum
Data
Checksum FFFF

Received Data

Source port	Destination port	Length	Checksum	DATA	DATA	DATA	DATA
4A97	89D4	F	FDB2	000E	00B7	0016	0055

Received Numbers

Exercise N2.
Data checking in UDP protocol.

Purpose:
Data checking in UDP protocol.
Received datagram should be checked and declined in case of an error. If the packet does not contain any errors it should be accepted.

Exercise Instructions:
To check the received data checksum should be calculated for the packet, after which it should be compared to the received checksum. For checksum calculation use the calculator in the right side of the window.
Received numbers should be checked if the datagram is accepted. Click "Check" button after writing down the data into "Received Data" field in decimal format separated by commas.

Received data is given in the top of the window. Received datagram should be checked and declined in case of an error. If the packet does not contain any errors it should be accepted.

The purpose of this exercise as well as short instructions are provided on the right side of the window.

Exercise Instructions

To check the received data checksum should be calculated for the packet, after which it should be compared to the received checksum. For checksum calculation use the calculator in the right side of the window. Data should be written in the hexadecimal format in **“IP Checksum”** and **“Data”** fields. Click the **“Calculate Checksum”** button. The calculated code in hexadecimal format will be displayed in the **“Checksum field”**.

If the received datagram is correct, frame will appear in the **“Received Data”** field after pressing **“Receive”** button. In case of error within the frame click **“Decline”** button, and next datagram will appear. If the **“Receive”** button is pressed when there is an error, the warning indicator will turn to red.

Received numbers can also be checked. Click **“Check”** button after writing down the data into **“Received Data”** field in decimal format separated by commas. If the numbers are correct, the dialog box will appear with “Correct!” text, the dialog with “Incorrect!” text will appear in opposite case. Clear fields in this case and repeat all steps.

The program gives also opportunity to create reports based on the exercise results in MS Word format. Click **“Report”** button to create the report.

If the exercise is not finished after **“Report”** button is pressed corresponding dialog will appear and the report will not be generated.

If the exercise is finished correctly, window will appear after pressing **“Report”** button to fill user's name.

The report includes protocol name, exercise number and purpose, user's name, date, as well as the image of constructed frame, depending on the purpose of the exercise. Save the file in any folder you want.